# East Midlands Sustainable Development Round Table

# The Potential Impacts of Climate Change in the East Midlands

Technical Report

August 2000

Entec UK Limited

# East Midlands Sustainable Development Round Table

# The Potential Impacts of Climate Change in the East Midlands

Technical Report

August 2000

Entec UK Limited

**Report for**

Dr Brian Waters
Regional Water Manager
Environment Agency
Sapphire East
550 Streetsbrook Road
Solihull
B91 1QT

**Main Contributors**

Jim Kersey, Entec
Dr Rob Wilby, University of Derby
Dr Paul Fleming, DeMontfort University
Dr Simon Shackley, UMIST

**Issued by**

...................................................................
Jim Kersey

**Approved by**

...................................................................
Stephen Billington

**Entec UK Limited**

Gables House
Kenilworth Road
Leamington Spa
Warwickshire
CV32 6JX
England
Tel: +44 (0) 1926 439000
Fax: +44 (0) 1926 439010

02800

document3

Certificate No. FS 32936

# Executive Summary

This study is the first step in understanding what climate change could mean to the Region and what we can do to minimise further climate change. This technical report is for the specialist reader and describes in detail the climate change models that were used, the impacts of climate change in the Region, the stakeholder discussions, the background to the Region and its greenhouse gas emissions. The study was commissioned by the East Midlands Sustainable Development Round Table and carried out by a team consisting of Jim Kersey, Entec (environmental consultants); Dr Rob Wilby, University of Derby (UD); Dr Paul Fleming, DeMontfort University (DMU) and Dr Simon Shackley, University of Manchester Institute of Science and Technology (UMIST). They were assisted by a number of contributors including Dorian Speakman and Sarah Mander (UMIST), Peter Webber, Helen Chadwick and Dr Patrick Devine-Wright (DMU) and John Shacklock (UD).

The main findings from the study are:

- The climate of the East Midlands has changed over the last century and is expected to change in the 21st century;
- In the last century temperatures across the Region increased by over 0.5°C. The pattern of rainfall has changed – by 1999 there was more rain in the winter and less in the summer. Sea levels have risen on the East Coast by between 1 and 2 mm a year and there were more storms in the 1990s than the rest of the 20th century; and
- Predictions of the climate in the 21st century show that there is the possibility of a further increase in the Region's temperature of up to 3°C by the end of the century and further changes in rainfall patterns. Sea level rise could be in the range 0f 28-83cm on the East Coast by the middle of the century. However, the figures for climate change should be seen as ranges of possible values and the output from the climate modelling in Chapter 4 is a range of values for possible climate changes.

These climate changes could have the following adverse effects:

- Less water available for domestic, industrial and agricultural purposes. This will mean that we will have to use water more efficiently and/or collect more winter water for use in the summer;
- More flooding on the coast and around rivers. This could cause more damage to land and properties and restrict where we can put new houses and commercial development. We could see more floods like the ones experienced in Northampton at Easter 1998;
- Changes in the types of crops grown in the Region;
- Higher temperatures could lead to deterioration in the working conditions for employees. We may have to modify our workplaces and homes to be more comfortable during hot periods. However, wider spread use of air conditioning could lead to higher energy use with increases in associated emissions;

- More summers like the hot summer of 1995 with its high temperatures, water shortages, droughts and associated stresses upon wetland habitats and agriculture;
- Damage to buildings through subsidence, as soils dry out due to higher temperatures and lack of water;
- Changes in the sorts of plant and animal species found in the Region. The Region's biodiversity is already under tremendous pressure; and
- An increase in the number of tourists in the Region. Increased temperatures could have the effect of attracting more people to visit the Region. This could lead to more erosion of the Region's top tourist attractions such as the Peak District National Park, as well as causing greater congestion due to increased traffic.

Depending on how we choose to deal with climate change, there could be opportunities for the Region:

- One of the sources of the main gas that causes climate change, carbon dioxide, is energy production. In April 2001 the Government will introduce an energy tax (the climate change levy) on businesses in order to reduce emissions. By using energy more efficiently and generating energy from renewable sources, such as wind and biofuels, businesses could reduce their energy costs and improve their commercial performance at the same time. This could give businesses in the Region a competitive edge as well as reducing emissions. The Government is also introducing £150 million worth of support for the uptake of clean and renewable energy technologies as part of the climate change levy. The Region's businesses could benefit from this too;
- The Region may be able to produce more energy from renewable sources. It could grow crops that could be used for energy production and produce no net greenhouse gas emissions;
- Agricultural and horticultural produce that is new to the Region could be grown and sold;
- Manufacturing and selling new technologies and equipment to reduce emissions and energy use and in other ways respond to climate change;
- Plants and animals could benefit from a different approach to managing the Region's environment such as increasing the amount of wetlands or managed realignment of the coastline. This could benefit certain birds and plants that are rare in the Region. Higher temperatures could encourage tree growth but the effect of an expansion of woodlands on water resources would have to be considered. The Region has one of the lowest amount of forests and woodlands in the UK;
- Higher temperatures could lead to more visitors to the Region and increased income from tourism;
- Lifestyles and health may benefit from a move to a more outdoors culture throughout the year, providing that the potential adverse health impacts from increased exposure to sunlight and air pollution are limited; and
- Reducing fuel poverty by allowing people on lower incomes to have affordable warmth through improving the energy efficiency of dwellings.

Overall, we will have to live with some level of climate change and plan accordingly. In order to do this we will have to take climate change into account when planning our water resources, flood defences, industry, agriculture, housing and other developments and biodiversity.

However, the priority for action is to avoid causing even more harmful changes in our climate. Climate change is caused by certain types of gases, called greenhouse gases, that we release into the atmosphere. The most important greenhouse gas, carbon dioxide, is produced when we burn fossil fuels – in our cars, our homes and in industry such as power stations. We need to reduce these releases drastically if we are to limit further damaging climate change. The consequences of these releases are felt around the world, because they contribute to climate change globally, not just in the East Midlands.

The people of the Region are concerned about climate change. They feel that it is the third most important issue facing the Region. There is support for action to be taken to deal with the consequences of climate change and avoid future change. There is also a recognition that climate change is just one of the many changes that are facing the Region. Other social, economic and environmental changes will have to be considered along with climate change in planning for the future of the Region.

The Region has a reputation for carrying out innovations to reduce greenhouse gas emissions, most notably in the areas of energy efficiency and renewable energy. However more work needs to be done and the Region should set itself tough targets for reducing the emissions of gases that cause climate change. The Region should also be monitoring climate change variables such as temperature and rainfall and the impacts on climate change of the Region's economic, social and environmental processes.

The following chapters give more details about climate change in the East Midlands.

# Contents

FIGURES

# 1. What is the Purpose of the Study?

*Main Author: Jim Kersey, Entec*

This study is the first step in trying to understand what may happen because of possible future climate change in the East Midlands. It was commissioned by the East Midlands Round Table and was written by Entec, the University of Derby, DeMontfort University and the University of Manchester Institute of Science and Technology (UMIST).

The overall objectives for the study were:

> *"The East Midlands wishes to position itself to minimise the risks to the local environment, economy and well being of its inhabitants and those beyond its boundaries, to take best advantage of the opportunities that may be there, and to play its part in the UK's work on lessening the effects of climate change."*

The study had several more specific aims:

1. To provide an overview of the best current information on the likely climate scenarios for the East Midlands;

2. To provide an overview of the existing information on the impacts on the environment, economy, and natural resources based on existing reviews, research and monitoring studies within and outside the Region;

3. a) To identify key stakeholders in the Region who will be most affected by climate (change);

   b) Assess their views on the likely impact on their interests;

   c) Report on how they expect to respond, including any plans for mitigation; and

   d) Assess their views on the local impact of Government emissions targets and mitigation measures (including any climate change levy).

4. To identify key information gaps and uncertainties in assessing the impacts and recommend ways to respond;

5. To identify priorities for research and information collection in developing a better understanding of the type and extent of potential impacts, as an input into developing a later, separate strategy for promoting ways to adapt to and mitigate climate change across the main areas and economic sectors in the Region. This work will need to take account of on-going studies funded by DETR, MAFF, the Environment Agency, English Nature, NERC, ESRC and other relevant public bodies;

6. To suggest targets and indicators of change which can be monitored; and

7. To disseminate the findings of the study through a conference/workshop for the main stakeholders.

The following sections address these aims.

There are two study reports. This report, the Technical Report, describes in detail the study's findings. The Technical Report is aimed at the more specialist reader and those involved in more detailed planning. There is also a Summary Report, which presents the general findings from the study and is aimed at the general reader and policy makers.

# 2. What is Climate Change?

*Main Author: Jim Kersey, Entec*

## 2.1 Climate Change – An Introduction

The earth's climate has been changing throughout its history. This has been mostly due to natural causes. The atmosphere must maintain the earth's temperature within an acceptable range in order to support life. This temperature range, along with the earth's geography (oceans, mountains, land masses etc), determines weather patterns. Weather patterns and geography, which influence biological support systems such as the availability of water, influence where and how people live.

The atmosphere maintains the temperature range by trapping a certain amount of the incoming energy from the Sun. The amount of energy that is trapped depends on the proportion of different gases in the atmosphere. The amount of energy trapped determines the earth's temperature. A particular mixture of gases maintains the temperature within the range that supports life. Changes in the proportion of gases can alter the earth's temperature and hence weather patterns. So the atmosphere needs a certain proportion of greenhouse gases (called greenhouse gas concentration) in order to maintain an acceptable temperature range and hence support life.

There are concerns that because human activities have lead to an increase in the levels of greenhouse gases in the atmosphere, the climate is changing beyond its natural variability. Climate change studies try to understand these changes and how they could affect us. This is done by looking at historical weather measurements, such as temperature and rainfall, and looking for changes beyond what can be considered natural. Computer based models are then run that try to describe the behaviour of global weather system due to increases in greenhouse gas levels. This is a complex task, as no model can hope to fully describe what is happening or could possibly happen with the weather. However the models are getting better and better and they are beginning to be able to describe what has happened historically and so scientists are becoming more confident that they are getting better at describing what may happen in the future.

These models produce a range of possible events or scenarios, as there is no exact answer to what may happen with the climate. They produce estimates of future climate such as rainfall and temperature. This information can then be used to estimate what the impacts of climate change could be such as the effect on water resources and flooding. Less rainfall could reduce water resources. This in turn could affect agriculture, industry and domestic supplies. More rainfall could increase flooding, leading to damage to buildings and land. Changes in temperature could lead to changes in agriculture with different types of crops being grown and changes in the length of the growing and harvesting season. Many animal and plant species are sensitive to climatic factors, so changes in temperature and rainfall could also affect flora and fauna.

So, the scenarios can be used to help plan future programmes that may be affected by climate change such as where people live, the need for flood defence and water storage. However, climate change is not the only change that is happening. There are other changes brought about by social and economic trends. In some cases climate change may have only a minor impact and in others it may be more significant. In some cases climate changes may be beneficial and in other it may be negative. Therefore consideration of possible future climate changes should be undertaken as part of the consideration of the wide range of issues that may affect organisations and people in the future.

In this study historical measurements of the East Midlands climate are examined to try to identify any trends in climate changes. Computer models have also been run to describe a range of possible scenarios for climate change in the future. The potential impacts of these climate changes are also described. These are presented in the following sections. The first section describes the evidence for climate change at the international and national levels and the organisations that have been set up to monitor and respond to climate change.

## 2.2 Progress with Climate Change at the International Level

The Intergovernmental Panel on Climate Change (IPCC) was set up in 1988 and is a joint organisation of the United Nations Environment Programme (UNEP) and the World Meteorological Organisation (WMO). It is a group of international scientists and policy makers who have been assessing the latest research and implications of climate change. Their second report on climate change in 1995 stated that observations suggest:

> *"a discernible human influence on global climate". This means that climate change is happening and that human activities (especially those that lead to greenhouse gas emissions) are contributing to this.*

The Chairman of the Intergovernmental Panel on Climate Change (IPCC), Robert T Watson, stated in his report to the Fifth Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) in Bonn, November 1999:

> "..let me remind you that it is not a question of whether the Earth's climate will change but rather *when, where and by how much*….".

Against the background of overall demonstrable climate change, much work is being undertaken to understand the specific "*when, where and how much..*" questions of climate change both at the UK national level and at the sub national/regional level.

The IPCC's third assessment report is being produced at present. It emphasises the importance of understanding the implications of climate change at the regional level. One of the organisations that runs computer models to estimate future climate change at the global level is the UK's Hadley Centre for Climate Prediction and Research. These models are used by the IPCC. The work of the Hadley Centre is briefly described in the next section.

## 2.3 Progress with Climate Change at the National Level

### 2.3.1 The Hadley Centre for Climate Prediction and Research

The Hadley Centre for Climate Prediction and Research, which is based at the UK's Meteorological Office, identifies global climate changes and makes climate change predictions using their computer based global circulation model. This has advanced our understanding of climate change and their 1999 report examined the effects of climate change, at a global scale, on natural ecosystems, water resources, agriculture, coastal zones and human health. At the international and national level the following observations have been made:

- 1997 was the warmest year, globally, since records began in 1860. The nine warmest years in the record have occurred since 1980;
- 1997 was also the third warmest year in the 300 year Central England temperature record. The 30 month period from April 1995 to September 1997 was the driest in England and Wales since records began over 200 years ago;
- If concentrations of greenhouse gases in the atmosphere continue to rise in line with recent trends, the Hadley Centre climate model predicts that global temperatures will rise by about $3^{o}$C over the next century. The more uncertain cooling effects of other emissions into the atmosphere may reduce this to $2.5^{o}$C;
- Analysis of past global temperature changes by the Hadley Centre confirms and strengthens the conclusions of the IPCC that human activities have begun to alter the global climate; and
- Atmospheric concentrations of most greenhouse gases continue to rise with particularly rapid increases observed for man-made industrial gases.

So there is strong evidence at the international level that human activities are having an influence on the climate. However, we need to try to understand what this could mean at the national and local levels. The next section, which discusses the work of the UK's Climate Impacts Programme, describes the work that is being done to understand the potential effects of climate change.

### 2.3.2 The UK Climate Impacts Programme

Climate change impact studies in the UK are now coordinated by the UK Climate Impacts Programme (UKCIP). UKCIP's role is to assist those carrying out impact studies to use common methodologies and assumptions in order to enable a common picture to be built of climate change impacts in the UK. UKCIP also encourages an integrated approach to impact studies to enable cross-sectoral impacts to be assessed and understood. UKCIP's Technical Report No1 "Climate Change Scenarios for the UK" Sept 1998, (using the information from the Hadley Centre's models) included the following conclusions:

- "Analysis of historic climate data in the UK confirms a warming of $0.5^{O}$C during the twentieth century, with decreasing numbers of cold days and increasing numbers of hot days. Trends in precipitation and gale frequencies are less clear."

- "Changes in climate variability and extreme events are likely to be more important for many impacts than simple changes in average climate…"
- "For some specific impacts studies, these national climate scenarios may need to be supplemented with more detailed regional scenarios constructed using a regional climate model or statistical downscaling techniques."
- "Major uncertainties about future climate prediction remain, including the rate of greenhouse gas emissions growth, the overall sensitivity of the climate system to human influence and the potential for rapid climate change."

Again, there is strong evidence that climate change is happening at the national level. UKCIP have developed a number of possible scenarios to illustrate the possible range of changes in climate. These scenarios have been used to model some of the possible future climates for the East Midlands Region. The results are presented in Chapter 4.

A number of studies have been, or are being, carried out to interpret these national findings at the regional level throughout the UK. These include studies for Scotland, the North West England, the South East England, Wales, West Midlands and East Anglia as well as a major conference on climate change impacts in South West England. Studies are also being carried out into sectors that could be vulnerable to climate change such as climate change and health. UKCIP are coordinating these studies. These studies have been reviewed in this study and information from them, where relevant, has been used in this technical report.

# 3. Characterisation of the East Midlands

*Main Author: Jim Kersey, Entec*

This section gives a broad description of some of the main economic, social and environmental features of the East Midlands. Climate change is just one of the issues facing the Region. There are other changes, such as socio-economic trends, that will also affect the Region over the coming decades. This section seeks to identify the issues that are of most relevance to climate change. Chapter 5 on the potential impacts of climate change in the Region, gives more details of how these features could be affected.

## 3.1 Overview

The following sections give a brief overview of the physical nature of the Region.

### 3.1.1 The Physical Context

The East Midlands Region covers approximately 1.5 million hectares, 12% of England's land area. Its population of 4.2 million is 7% of the UK total. It includes the counties of Leicestershire, Nottinghamshire, Lincolnshire, Derbyshire, Northamptonshire and Rutland. The East Midlands Region has considerable landscape and geographical variety. This extends from the upland moorland landscape of the Peak District, through the central farmlands of Northamptonshire and Nottinghamshire, river valleys such as the Trent, to the low flat landscape of the Lincolnshire Fens running down to the North Sea coast. Two of the UK's major estuaries are adjacent to the Region – The Wash and The Humber.

### 3.1.2 Sub Areas

In order to reflect the diversity of the Region, the Regional Planning Guidance (RPG) divides the Region into 5 sub-areas:

- Southern. This consists of Northants and the southern portion of Leicestershire (Market Harborough etc). It has experienced rapid growth over the last few decades due in part to its location near to the South East, West Midlands and European regions;
- Three Cities. This consists of the major administrative, commercial and cultural centres – Derby, Leicester and Nottingham. Whilst providing economic growth they also contain areas of deprivation. East Midlands airport is also within the sub-area. The 3 cities are well connected to the M1 – the major north-south road link in the Region;
- Peak. This consists of the Peak District National Park (a key national asset – the most visited in Europe) and the surrounding area. Predominately rural but adjacent to major cities eg Sheffield and Manchester;

- Northern Coalfields. The industrial decline, due mainly to the closure of coal mining operations, has affected settlements of all sizes from large towns (Mansfield and Chesterfield) to rural villages; and
- Eastern. This consists of Lincolnshire, Rutland and the eastern parts of Nottinghamshire and Leicestershire and includes dispersed towns and rural hinterland. Some parts of this sub-area are remote. Major settlements are Lincoln, Grantham, Newark-on-Trent and Boston.

The physical characteristics of the Region include:

- The Region has a number of large cities and towns but has not seen the widespread urban sprawl experienced elsewhere in the UK. Most of the urban centres are vibrant, due in part to the absence of a major out-of-town retail centre;
- Parts of the Region are near to or adjacent to conurbations eg South Yorkshire, Greater Manchester and Coventry/Birmingham. Out commuting to these areas is increasing; and
- Some parts of the Region are relatively inaccessible, regionally and nationally eg the Eastern and Peak sub areas.

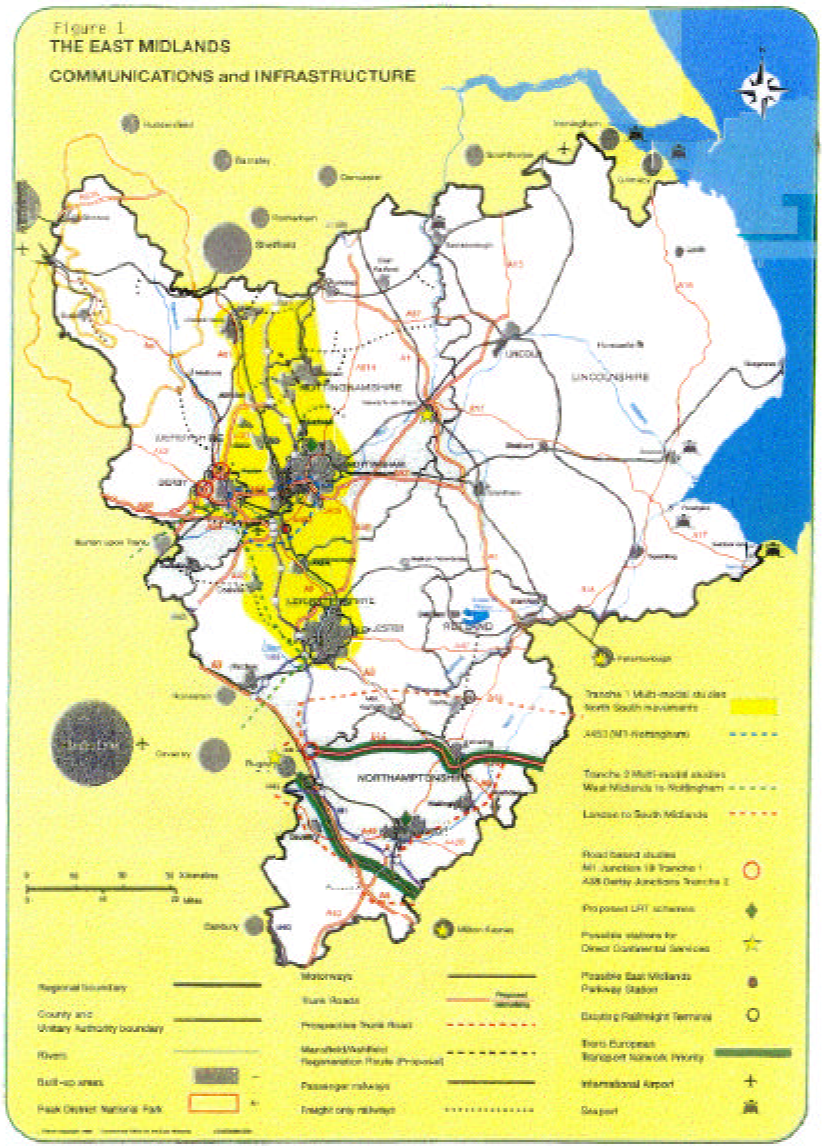
The distinctive character of the Region is under pressure from both modern farming and forestry practices, development and visitor pressure. These pressures can erode natural and man made features. Climate change could add to these pressures.

### 3.1.3 Infrastructure

Figure 1 shows the communications and infrastructure in the East Midlands. *(Reproduced with kind permission from Government Office for the East Midlands)*

The main infrastructure features of the Region are:

- The main north-south routes in the Region (M1, A1 etc) are increasingly congested. The proximity of settlements to the M1 and the resulting economic development, have encouraged the use of the private car and road freight movements, despite the Region's public transport links. The Midland Main Line rail runs north-south between a number of the Region's major settlements. The East Coast Main line also passes through the Eastern part of the Region. The Channel Tunnel Rail Link to St Pancras will benefit rail passengers in the East Midlands as it will be adjacent to the terminus for both the Midland Main Line at St Pancras and Kings' Cross. The Region has existing and developing railfreight facilities such as the Daventry International Railfrieght Terminal and the Corby Eurohub;
- Two of the European Union's Trans-European Network routes (TENs) pass through the south of the Region – the West coast Main Line and the Ireland/UK/Benelux road route (A14);
- East Midlands Airport provides international links. An extension to the runway will provide facilities for longer distance flights. Passenger and freight traffic to and from the airport is predicted to grow substantially; and




- The Region also has a number of small ports – Boston, Fosdyke, Sutton Bridge (all on the Wash) and Gainsborough (on the navigable Trent). They have the capacity to serve the wider Region. Boston has a dockside rail connection, and has potential for expansion, especially if the dock entrance can be widened. The Region is also near to some large ports: on the Humber (Grimsby and Immingham); and in East Anglia (Harwich and Felixstowe). These provide growing freight links to the rest of Europe and beyond. This is of particular importance to the East Midlands.

Climate change could result in changing rainfall patterns, increasing temperatures, rising sea levels and more storminess. These changes could in turn affect the physical features of the Region eg rising sea levels and storms could accelerate coastal erosion and damage infrastructure such as coastal and estuary ports. Rising temperatures could result in damage to transport infrastructure eg buckling of railway lines and increased melting of tarmac. Changing rainfall patterns could result in more flooding and hence erosion and inundation of roads and other infrastructure.

Increases in traffic volume in the Region contribute to an increase in the emissions of greenhouse gases that contribute to climate change. This is discussed in more detail in the chapter on greenhouse gas emissions in the Region.

## 3.2 Economy

### 3.2.1 Overview

As far as the UK is concerned, the East Midlands economy "would appear, in overall terms, to be relatively successful" [Draft RPG Nov 1999]. It has:

- Been growing more rapidly than the UK average for nearly 20 years – its share of UK GDP has risen from just above 6.1% in 1980 to nearly 6.7% in 1998;
- Had consistently lower unemployment than national or European average;
- Shows considerable diversity. The following vary widely throughout the Region – economic performance, economic structure, unemployment and rates of business formation;
- A larger than the national average manufacturing sector;
- A large and diverse small firms base;
- A consistently high score on measures of quality of life; and
- A pattern of compact urban development and well connected rural areas with a strong network of market towns.

However, there are some real problems:

- GDP per capita is below national and European levels – 94% of UK and European per capita;
- Suffers low productivity, partly as a result of the Region's unfavourable industrial structure;
- Concentration of industry in traditional manufacturing sectors;
- Under-represented in growth sectors such as telecommunications (electrical engineering and communications), finance and business sectors;
- Below average workforce skills, levels of educational attainment and average earnings;

- Lack of investment in skills, research and innovation;
- Some areas are facing major regeneration challenges including some urban areas, the coalfields and rural communities. Many of these come from a legacy of industrial decline; and
- Hasn't performed particularly well in attracting inward investment.

There are wide variations across the Region. Some parts perform well, others are reliant on declining sectors. This means that some areas are performing significantly worse than the Regional average. These areas include: some urban areas of Nottingham, Leicester and Derby; the former Nottinghamshire/Derbyshire coalfield; the Lincolnshire coastal resorts; and some rural areas.

It has been said that the East Midlands performs well in spite of its industrial structure not because of it.

The following table gives a breakdown of the industrial structure in the East Midlands for 1998.

**Table 1 Industrial Structure of the Region**

| Industry | Share of Employment % | | UK Output growth rates | |
|---|---|---|---|---|
| | East Midlands | UK | 1976-82 | 1982-93 |
| Mining excluding oil and gas | 1.5 | 0.1 | -1.4 | -4.2 |
| Electricity and water supply | 0.6 | 0.6 | 1.8 | 2.8 |
| Fuel processing | 0.4 | 0.1 | -2.4 | 1.6 |
| Chemicals and man made fibres | 1.4 | 1.1 | -0.6 | 3.9 |
| Minerals | 0.9 | 0.6 | -3.0 | 1.0 |
| Metals | 2.7 | 2.3 | -4.4 | 0.4 |
| Mechanical engineering | 2.5 | 1.7 | -3.8 | -0.4 |
| Electrical engineering | 1.8 | 2.2 | 0.7 | 5.1 |
| Transport equipment | 2.1 | 1.7 | -2.5 | 1.2 |
| Food, drink and tobacco | 3.5 | 0.2 | 0.6 | 1.0 |
| Textiles, footwear and clothing | 5.0 | 1.4 | -3.8 | -0.3 |
| Wood and wood products | 0.5 | 0.4 | -3.4 | 2.0 |
| Paper, printing and publishing | 2.1 | 0.2 | -1.0 | 3.3 |
| Rubber and plastics | 1.3 | 1.0 | -2.0 | 4.9 |
| Other manufacturing | 1.5 | 0.9 | -6.3 | 0.1 |
| Retailing | 9.3 | 10.1 | 1.2 | 3.2 |
| Other distribution and hotels | 12.4 | 12.6 | | 3.3 |
| Transport | 3.4 | 3.9 | 0.2 | 2.5 |
| Communications | 1.5 | 2.0 | 4.2 | 4.4 |
| Banking and finance | 2.3 | 4.3 | 1.3 | 2.9 |
| Business and other financial services | 10.3 | 11.9 | 5.8 | 5.9 |

| Industry | Share of Employment % | | UK Output growth rates | |
|---|---|---|---|---|
| | East Midlands | UK | 1976-82 | 1982-93 |
| Property, research and renting | 1.8 | 2.2 | 5.1 | 0.5 |
| Public administration | 4.4 | 5.6 | -0.3 | -0.2 |
| Education and health | 18.3 | 18.6 | 1.3 | 1.2 |
| Other (largely private) services | 4.1 | 4.6 | 2.3 | 4.2 |

EMDA: Prosperity through People, Supporting Analysis 1999 - Business Strategies. Figures are growth rates of a 3- year moving average between cyclically comparable points. Agriculture and construction are excluded.

The table shows that sectors that have performed poorly at the national level are relatively large in the East Midlands – mining, fuel processing, metals, minerals (mainly building materials), mechanical engineering, transport equipment (cars, aerospace, trains) and textiles, footwear and clothing.

It also shows that the Region is under-represented in the more rapidly growing sectors such as: electrical engineering (mostly electronics); communications; finance; business services; property, research and renting; and personal services.

Traditional industries such as manufacturing tend to be more energy intensive than the newer sectors such as communications and finance. In April 2001 the Government is introducing an energy tax on business. The Region could see its energy bill increase substantially unless it takes steps to reduce energy consumption and develop and use energy from renewable sources. Renewable energy will not be subject to the tax. This means that renewable energy could cost less than energy generated from traditional fossil fuel sources. Improving energy efficiency can also help to improve the competitiveness of business. The Government also has targets for reducing emissions of greenhouse gases. Chapter 9 on greenhouse gas targets and indicators discusses this in more detail.

### 3.2.2 Agriculture

The better quality agriculture land in the Region is located to the east, particularly surrounding the Wash. The poorer quality agricultural land is located in the west in Derbyshire and the Peak District.

Overall, agriculture employs 2.4% of the Region's workforce. This rises to 6.8% in the predominately rural counties such as Lincolnshire, reflecting the Region's rural nature. Apart from those directly employed in agriculture, there is significant employment in related industries such as food processing and agricultural engineering. This adds to the importance of agriculture in the Region. Also, lack of alternative employment in rural areas increases the dependency on agriculture.

Changes to temperature and rainfall patterns could reduce water availability and hence affect agriculture, especially those crops that require significant irrigation. Increased temperatures could lead to increased heat stress amongst livestock and unfavourable working conditions for farm workers. The Region could see changes in agricultural patterns. This could be in part a response to climate change but will also be in response to consumer demand, agricultural innovations and changes to farming support eg reform of the EU's Common Agricultural

Policy. Increased coastal flooding and intrusion of salt water could damage agricultural land and crops adjacent to the coast.

### 3.2.3 Tourism and Leisure

In some parts of the Region eg the Peak District and the Lincolnshire Coast, tourism is a major employer. The tourism and leisure sector continues to expand, providing further potential for employment growth. The sector is often perceived as having poor employment conditions – low pay, subject to seasonality and poor job security. These are particular issues in the Eastern sub-area.

Most tourism in the Region is short breaks and day trips from surrounding conurbations and is dependent on the Region's many sites of historic and cultural interest eg Belvoir Castle, Lincoln Cathedral, Sherwood Forest and Chatsworth House and historic battlefields such as Bosworth and Naseby. The Region also has a number of international and national sports venues eg the National Water Sports Centre at Holme Pierrepont, the National Sports Centre at Loughborough, Rutland Water, motor racing circuits at Silverstone and Donington, the cricket Test Match venue at Trent Bridge and large football stadia in Derby, Leicester and Nottingham. These all regularly attract visitors for various events.

Other developments in the Region may attract visitors for recreational purposes such as the SUSTRANS National Cycle Route, the National Forest, Greenwood Community Forest and other woodland schemes and the River Nene Regional Park. There are about 455 miles of navigable waterways in the Region, including the Witham and Nene rivers. Ten million people visited inland waterways in 1998 (British Waterways). They are of growing importance as a tourist attraction.

Warmer periods could increase the numbers of tourists. This is an economic opportunity for the Region but there could be negative impacts such as increased erosion of popular sites due to increased visitor numbers and increased traffic. Increased tourism opportunities will therefore have to be managed appropriately if the adverse impacts are to be minimised.

### 3.2.4 Energy

There is an above average concentration of power generation in the East Midlands compared to other UK regions. Major power stations in the East Midlands are West Burton (coal), High Marnham (coal), Ratcliffe-on-Soar (coal), Willington B (coal), Cottam (coal, and combined cycle gas turbine (from 1999)), Sutton Bridge (combined cycle gas turbine (from 1999)), Corby (combined cycle gas turbine), and Derwent (CHP) (DTI, 1999a).

These power stations produce large amounts of electricity for regional and national consumption. This is due in part to their proximity to fossil fuels, cooling water and the electricity distribution grid. These power stations are significant producers of greenhouse gases. This is discussed in more detail in the chapter on greenhouse gas emissions in the Region.

Renewable energy technologies can produce energy without greenhouse gas emissions and estimations have been made on how much renewable energy can be generated in the Region. The Regional Planning Guidance (RPG) has a target of working towards 400MW of grid-connected renewables by 2005. The Region's land use patterns and proximity to major markets eg Birmingham/Coventry, the South East and South Yorkshire, could put it in a good position to develop renewable energy schemes. More work will need to be done to assess the exact nature of the potential for renewable energy development in the Region.

## 3.3 Social Conditions

### 3.3.1 Population

The East Midlands has a higher population density than the UK average. Between 1981 and 1997 the Region's population grew by 8% to 4,156,300. The population change ranges from a 13.5% growth in Northants to a decline of 0.8% in the Peak District National Park. One in three of the Region's population live in rural areas. This is higher than the national average. The Region's rural population has grown by 7.6% since 1981. The Region is experiencing urbanisation rates of 5000 hectares per year.

### 3.3.2 Social Deprivation

Some social conditions are closely linked to economic conditions due to the availability of jobs and hence household income, so the East Midlands scores reasonably well on a range of social indicators. It lags behind the South East (as do most regions) but performs better than many other regions. Some areas have serious social exclusion and deprivation problems such as the Region's larger towns and cities, the former coalfields areas and peripheral and isolated communities. The Region contains two Objective 5b areas (areas that attract support in the form of special funding through the Government) – one is the Midlands Uplands which includes the Peak District and the other is parts of Lincolnshire. One Objective 2 area covers the North Derbyshire and North Nottinghamshire Coalfield area and parts of the City of Nottingham.

The following table shows how East Midlands local authorities are ranked on the Index of Local Deprivation for English local authorities. This is a weighted index of 12 indicators including those related to income support, mortality, educational attainment, crime and housing conditions.

**Table 2 The Region's Settlements in the Top 100 of the Index of Local Deprivation**

| Local Authority | Position |
|---|---|
| Nottingham | 16 |
| Leicester | 32 |
| Lincoln | 46 |
| Mansfield | 67 |
| Derby | 71 |
| Bolsover | 86 |
| Chesterfield | 91 |
| Ashfield | 93 |

Only eight of the Region's 40 districts appear in the first 100. Eighteen of the Region's 40 districts, fell outside the 200 most deprived districts. Overall the Region's larger cities perform worse in the Index. Towns in former coalfield areas are also prominent. Lincoln, with a rural hinterland, also performs poorly. These ranking reflect the issues affecting the Region – some areas of declining industries, rural isolation and problems affecting cities.

Little work has been done on the possible impacts of climate change on social conditions. Areas that could benefit from further investigation include the impact of climate change on rural communities and inner cities eg the economic impacts of flooding on low-income households, the link between fuel poverty and climate change eg the need for increased cooling in hot periods and changing employment patterns eg agriculture and tourism.

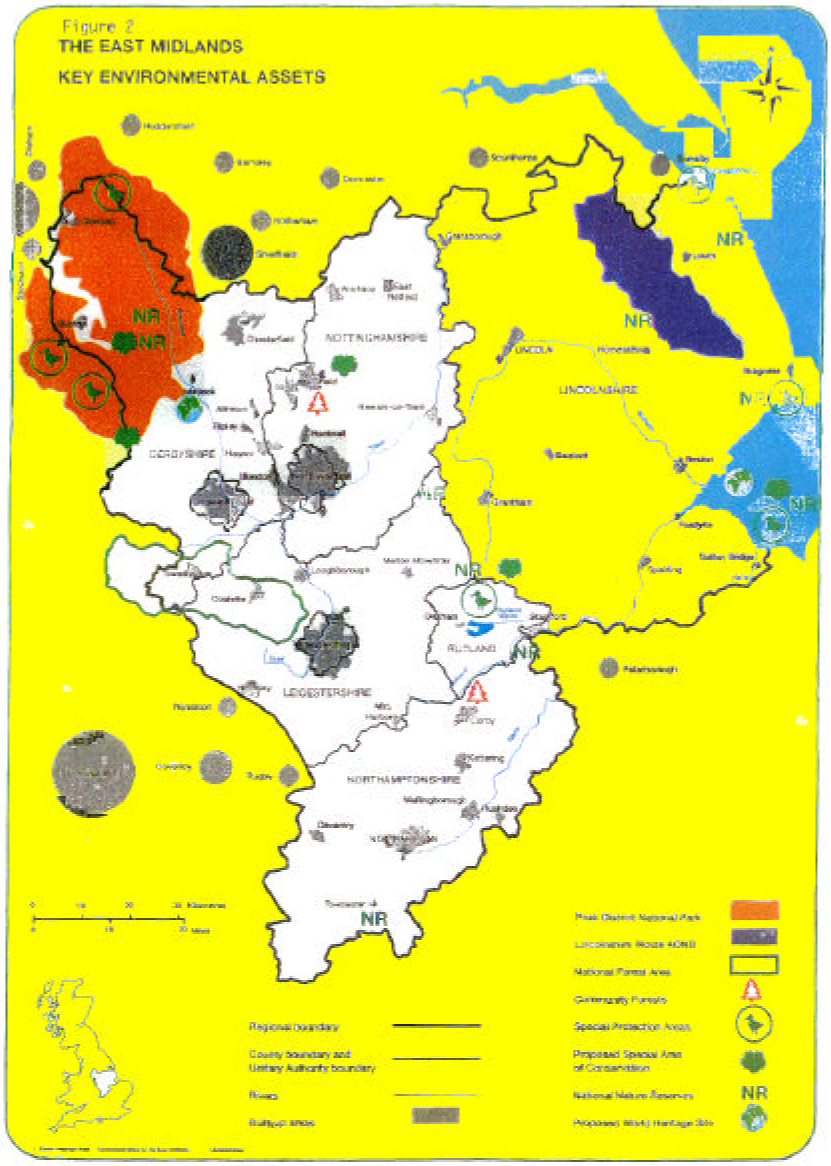
### 3.3.3 Housing

Due to trends in the reduction of household sizes, inward migration, economic development and replacement of existing stock, it is estimated that the East Midlands will need approximately 363,000 new houses by 2021. All five counties have approximately the same share of this provision.

County structure plans identify suitable areas and criteria for this provision but possible future climate change impacts should be taken into account in the planning and decision making process. For example, climate change could change flooding patterns. Development in floodplains could then be subject to increased risk of damage. Climate change could also affect the availability of water resources and biodiversity. These possible effects will need to be considered when identifying possible locations for development. The Department of the Transport, Environment and the Regions is planning to carry out a study into how the planning system could consider the impacts of climate change.

## 3.4 Natural Environment

Figure 2 shows the East Midland's key natural environmental assets. *(Reproduced with kind permission from Government Office for the East Midlands)*




A high proportion of the Region is rural. This provides recreational opportunities for residents and visitors. The Region contains the Peak District National Park and the Lincolnshire Wolds Area of Outstanding Natural Beauty (AONB), both nationally and internationally important.

The following sections consider various aspects of the Region's environment and the possible consequences of climate change.

### 3.4.1 Biodiversity

The East Midlands has seen a serious reduction in biodiversity over recent years. This has been exacerbated by widespread loss of woodlands, hedges, heathlands, wetlands and species rich grassland. The following extract from "Sustainability and Biodiversity, Priorities for Action in the East Midlands" produced by the East Midlands Regional Biodiversity Forum, April 1999 details the main biodiversity issues for the East Midlands:

- Species of international importance present in the Region include: spined loach, gadwall, great crested newt and natterjack toad;
- The Peak District National Park, the Lincolnshire Coast and the Wash contain areas outstanding at the European level because of the diversity of special wildlife habitats;
- In the rest of the Region biodiversity has declined perhaps faster than almost anywhere else in Britain. This is because of much of the Region is high quality farmland whose management has intensified since the Second World War. Examples of this are:
    - Apart from Derbyshire, less than 2% of the land area is a Site of Special Scientific Interest (SSSI). The national average is 7%. In Leicestershire, Northamptonshire and Nottinghamshire, 70% of scarce plant species have become extinct since 1970;
    - The Region has half the national average woodland cover;
    - Since 1920, 88% of the remaining heathland in Lincolnshire has been lost to afforestation, agriculture and built development;
    - Farmland birds have declined by up to 85% within 25 years;
    - Grasslands of high conservation value have been ploughed or improved, even in the Peak District National Park; and
    - The vast wetlands of the Lincolnshire fens have been drained.

There are a number of initiatives that are being taken to either halt of reverse these trends such as:

- The On Trent Initiative – a partnership looking at the restoration of the natural habitats of the Trent Floodplain; and
- The Lower Trent Otters and Rivers Project with the aim of liaising with farmers to create wetlands and improve riverside habitats.

Increasing temperatures, changing rainfall patterns, sea level rises and flooding due to climate change could place additional pressures on the Region's existing flora and fauna species. The actual impacts of climate change on biodiversity will depend on how the Region chooses to adapt to climate change. Traditional approaches to flood defence i.e. hard, constructed sea and river defences, could increase the negative impacts on biodiversity as it could lead to further loss of habitats. However, adaptations that involve the use of more natural processes, such as managed re-alignment, will probably have benefits for the Region's biodiversity.

### 3.4.2 Water

**Water Resources**

Surface water abstraction from rivers and reservoirs provides a large proportion of the East Midlands public water supply, whilst limestone, chalk, carboniferous limestone and sandstone aquifers are also important in Lincolnshire and the Trent catchment. Groundwater provides 80% of Nottinghamshire's public water supply. Water is supplied to the major urban regions from the Derwent Valley (Ladybower Reservoir to Leicester and Derby), from Rutland Water (Leicester) and from other reservoirs. The Rivers Trent and Derwent are both major sources of drinking water. There are some water transfer schemes in the Region, including the Trent-Witham-Ancholme Transfer Scheme, which is of strategic importance to the surface water resources and abstractions within Lincolnshire.

Extraction of water from aquifers has reduced that available to support baseflow and wetland habitats. Many aquifers in the East Midlands are now considered to be fully committed to existing water abstractions and most of the surface catchments are fully licensed in the summer. The water companies are forecasting a reduction in Water Available for Use (WAFU) as a result of planned groundwater licence reductions (to alleviate stressed aquifers) and in response to climate change.

Increased temperatures and changing rainfall patterns could lead to reduced water available for use in the Region. In order to understand these effects more fully the water companies are running models of the potential impacts of climate change on their water resources. Chapter 5 discusses this in more detail.

**Water Quality**

The East Midlands has long stretches of 'good' and 'fair' quality rivers (40.5% and 51% respectively). The River Trent has gone from 'poor' to 'fair' over the last 30 years. The main pollution entering the rivers is from sewage works operated by the water companies. All seven of the EC defined Bathing Waters complies with the Bathing Water Directive (76/160/EEC). The vulnerability of many aquifers in the Region to pollution is regarded as being 'high' to 'intermediate'. Lower water levels in rivers could lead to reduced water quality as there could be less water to dilute discharges (see Chapter 5).

**Flooding**

Flood risk is high for floodplains of major rivers such as the Trent, Derwent, Soar, Witham and Nene. 15% of the East Midlands is vulnerable to 1:100 year floods (assuming no flood defences are in place). 1460km$^2$ of Lincolnshire is protected from tidal flooding and without the flood defences to protect it, would be regularly flooded. Much of this is valuable high-grade agricultural land.

Changing rainfall patterns, including more extreme rainfall events, and sea level rise could lead to changing patterns of flooding and associated damage to land and property in the Region (see Chapter 5).

### 3.4.3 Air Quality

Air pollution in the Region comes from two main sources – transport and industry. Pollution from industry has declined over recent years and the worst locations for air quality are generally those most affected by road traffic. Transport is also a major, and growing, source of greenhouse gas emissions.

### 3.4.4 Land Use

The following table gives the land uses in the Region:

**Table 3 The Region's Land Uses**

| Land Use | % |
|---|---|
| Arable | 53.5 |
| Managed Grassland | 29 |
| Urban | 11.5 |
| Forestry and Woodland | 5.5 |
| Inland Water | 0.5 |

Agriculture is the largest land use in the Region with a total agricultural area of 1,229,000 hectares. This is 13% of England's agricultural land. Agriculture employs 47,000 people and it is especially important in West Derbyshire and Lincolnshire. There are a wide range of agricultural activities from rich Lincolnshire peatlands, Nottinghamshire sands, Peak District moorland and pasture and the mixed farming of Leicestershire and Northamptonshire.

The following agricultural trends are occurring in the Region:

- Smaller numbers of larger farms;
- A decrease in total agricultural area (about 20% decrease between 1963-1996);
- More arable crops (eg 9% increase in cereals in East Midlands between 1963-1996);
- Largest decreases have occurred in temporary grass and (to less extent) permanent pasture;
- Increase in 'hobby farming' and small holdings on the urban fringe; and
- Increase in environmentally-conscious farming (environmentally sensitive areas (ESAs), Countryside Stewardship, woodland, organic conversion, etc).

The current rate of urbanisation in the Region is 5000 ha per year. The potential impacts of climate change on agriculture in the Region have been briefly outlined above.

**Underlying Soil Types**

The East Midlands soil types have properties that could make them vulnerable to climate change, either because they are not freely draining and hence prone to flooding, they require significant irrigation or are prone to erosion. Whether they will actually be prone to flooding or erosion will depend not only on climate change but also on: management practices eg crop management and drainage; other factors such as location (slopes and other landscape features); and surrounding land uses that may increase the risk of flooding eg built up areas that produce run off from storms from their hard surfaces. The following section describes the main soil types, their uses and their vulnerability to climate change:

- Loamy and clayey soils are the most common type being found throughout the Region. They are usually artificially drained and used for producing cereals, oilseed rape or livestock grass fodder. They are prone to flooding and to pollution from run-off. The clay soils are also the soils most susceptible to shrinkage during droughts;
- Sandy, loamy and clayey soils are the next most common and found especially in mid and coastal Lincolnshire. These soils generally require drainage and prone to flooding. Some areas support highly fertile agriculture and horticulture;
- Freely drained loamy soils range from Humber warplands to lowland river terraces and base-rich grasslands of the Dales and Wolds. Fertile agriculture is common;
- Shallow loamy soils (most over limestone and chalk) occur predominantly in a north-south strip through Lincolnshire. These soils are used mainly for agriculture and prone to rapid erosion when on slopes;
- Peaty soils support moorland and grassland in the uplands of the Peak District. The soils also occur in a few areas of Lincolnshire, where they are drained and used for horticulture. Reduction of black lowland peat soils has taken place through oxidation and windblow and at current rates of erosion they will disappear by the 2030s; and
- Sandy, freely-drained soils (mainly over sandstone) support intensive farming in the Sherwood Forest. Low water holding capacity means that irrigation is common.

Maintenance of the stock and fertility of these soils is crucial as, not only do they support the land uses in the Region including agriculture, but they also help to determine agricultural water demand and flooding patterns. Soil type alone is not the only factor that will determine whether there is a risk of adverse impacts from climate change, as discussed in the introductory paragraph to this section. Good management practices will help to reduce these risks.

### 3.4.5 Woodland and Forestry

The East Midlands has lower than the national average woodland cover (4.8% compared to 8%), varying from 7% for Nottinghamshire to 4% for Derbyshire and Leicestershire and Rutland. 56% of the woodlands are broadleaved, conifers are 34% and 10% are mixed. 16% of the woodlands are ancient - eg oak, ash or field maple woods. These ancient woodlands are found in Northamptonshire, Leicestershire and upland Derbyshire. Lincolnshire has some important woods such as the ancient limewoods around Bardney.

Whilst the woodlands of the Region are in general good health, there is some evidence of "dieback" in the more arable eastern areas of the Region, which has been linked to agricultural practices and drought.

Climate change could actually be beneficial to woodlands and forestry in the Region, due to increased $CO_2$ levels and increased temperatures making growing conditions more favourable. This could benefit the forestry initiatives in the Region such as the National Forest. Tree cover could also provide shading and shelter from higher temperatures for animals and buildings. There could also be associated benefits such as the extension of habitats for woodland flora and fauna. However, consideration would also have to be given to the impacts of increased forestry and woodlands on water resources and quality, in possible droughty conditions.

### 3.4.6 Cultural Heritage

The following is a list of significant cultural and heritage sites in the Region:

- Nearly 30,000 buildings of Special Architectural or Historic Interest;
- More than 1000 Conservation Areas;
- 111 entries on English Heritage register of Historic Parks and Gardens;
- Five historic battlefields;
- In 1996, there were 1205 sites scheduled as Ancient Monuments by the Secretary of State but this is less than 2% of the buildings in the Sites and Monuments Records (SMRs) maintained locally; and
- Derwent Valley are bidding to be designated as a World Heritage Site. Another possible candidate is Creswell Crags on the Nottinghamshire/Derbyshire border.

The issues affecting these sites include:

- The 1995 Monuments at Risk Survey found that 15% of all recorded monuments in East Midlands and East Anglia had been destroyed since 1945;
- The most significant factor in the degradation of the archaeological resource is agriculture and development; and
- In Lincolnshire, coastal erosion is a threat to sites and remains.

Historic and contemporary buildings could be at increased risk due to the impacts of climate change. Drought could increase soil shrinkage and subsidence. Indirect impacts could include increased pressure on cultural and historical sites from increased visitor numbers.

### 3.4.7 The Environment Agency's East Midlands Local Environment Agency Plans (LEAPs)

LEAPs are produced by the Environment Agency in order to identify and address the environmental priorities that fall within their regulatory duties and responsibilities. The plans are based on river catchments. The following table indicates the East Midlands catchments for which LEAPs have been produced and the areas they cover.

**Table 4 Local Environment Agency Plans and their Coverage**

| LEAP Catchment | Area |
|---|---|
| Soar | Mainly Leicestershire with small parts in Rutland, Warwickshire and Nottinghamshire. |
| Lower Trent and Erewash | Mainly East Nottinghamshire with significant portions of Derbyshire and Lincolnshire and small parts of Leicestershire and South Yorkshire |
| Idle and Torne | West Nottinghamshire, parts of Derbyshire, Lincolnshire and Yorkshire (Doncaster and Rotherham) |
| Derbyshire Derwent | Mostly Derbyshire from Buxton and Castleton to the city of Derby. Small part of Yorkshire (Sheffield). Includes some of the Peak District National Park |
| Dove | West Derbyshire and Staffordshire. Includes some of the Peak District National Park |
| Witham | Mostly Southern Lincolnshire with small parts of Leicestershire, Rutland and Nottinghamshire |
| Grimsby Ancholme | Mostly North and North East Lincolnshire (to the Humber) |
| Louth Coastal | East Lincolnshire |
| The Wash | The Wash |
| Nene | Northamptonshire, Lincolnshire, Cambridgeshire, Norfolk, Huntingdonshire and Bedfordshire |
| Welland | South Leicestershire, South Lincolnshire (to the Wash), parts of Rutland and small part of Cambridgeshire (Peterborough) |

The following sections list the actions in the plans that could be affected by climate change. Whether they will be and, if so, to what extent, will need to be the subject of further study.

**Soar**

The action plan was produced in June 1998. The following actions (the number of the action in the action plan is in brackets) that were identified as priorities could be affected by climate change:

- Biodiversity protection (1)
- Lack of compensation flows from public water supplies (5)
- The loss of wetland resources along the Soar Valley (6)
- Some stretches of river are either marginal or fail their proposed River Quality Objectives (RQO) (10)

- Flooding in the Soar and Wreake Valleys (13)
- Recreational access along the River Soar (20)
- Lack of definition of floodplains (21)

Of these issues those most vulnerable to climate change appear to be those relating to biodiversity, water resources, water quality and flooding. More work needs to be done to assess exactly what the impacts could be.

**Lower Trent and Erewash**

This plan was produced in April 1999 and the priority actions with most relevance to climate change are:

- Reduce greenhouse gas emission from a landfill site in Gainsborough (1)
- Potential environmental damage through over-abstraction in the plan area (5)
- Low flows in the Dover Beck (6)
- Biodiversity of local fauna and habitats (7 and 8)
- Potential effects of climate change on flood defences [particularly on the Humber Estuary](12)
- Poor water quality in the Bottesford Beck (17)
- Flood defence strategy to reflect changing land use (19)
- Recreational potential of rivers in the plan area not fully exploited (20)
- Potential damage of the archaeological resources of the River Trent corridor (24)

**Idle and Torne**

This plan was produced in November 1999 and the priority actions with most relevance to climate change are:

- Balancing the needs of the environment with the needs of surface water abstractors (2)
- Low flows in the LEAP area (3)
- Loss of wetland status of conservation sites in the LEAP area (4)
- The need to optimise the compensation flow from the public water supply shaft at Manton into the River Ryton (5)
- Impact of the abstraction of water from the River Ryton for the Chesterfield Canal (6)
- Lack of water resources to meet agricultural demand (10)
- Lack of recreational access along watercourses (12)
- Biodiversity of local species and habitats (17 and 18)

- The extent of floodplains are not clearly defined (22)

The issues most vulnerable to climate change appear to be 4, 10, 17 and 18.

**Derbyshire Derwent**

This plan was produced in January 1999 and the priority actions with most relevance to climate change are:

- Problems of maintaining current water quality levels in the Lower Derwent (4)
- Negative impact on natural brown trout populations in the Rivers Ashop and Noe caused by the operation of abstractions associated with the Derwent Valley reservoirs (6)
- Loss of habitat to invasive plant species (13)
- Promotion of recreational access along river valleys (15)
- The rich archaeological and historical resource of the Derwent valley requires protection (16)
- Biodiversity protection (18)
- The risk of flooding to undefended properties and to properties where existing flood defences require enhancement (23)
- Control of the development of the floodplain (24)

**Dove**

This plan was produced in March 2000 and the priority actions with most relevance to climate change are:

- Flooding along the Lower Dove Valley (2). Action is to provide defences for a 1 in 100 year event to Old Marston Lane at Hatton/Tutbury
- Impacts of tourism on the landscape and ecological habitats of Dovedale (7)
- Developments within floodplain including development along the A50 corridor (8). Applies to Derbyshire portion
- Changes in agricultural land use (9)
- Loss of habitat diversity in the lower reaches of the Dove catchment (10)
- Dove catchment abstraction licensing policy (17)
- Sustainable river bank management (18)
- Water level management plans (19)
- Biodiversity in the Dove catchment (20)
- Water quality objectives, standards and Directives (21). Applies to the Dove

- Investment by Severn Trent Water Ltd to improve water quality (23)

**Witham**

This draft LEAP was published in September 1999 and the priority actions with most relevance to climate change are:

- Rivers flows can be reduced by licensed abstraction to levels where environmental degradation occurs (1a). Low flow periods such as summers and droughts have been extended or exacerbated
- There is concern regarding the sustainability of proposals to restore for navigation purposes the Slea Navigation and the Horncastle Canal (1b). Local water resources in the catchments of the Slea and Bain are scarce in summer months and cannot sustain any increase in abstraction. Any proposal for restoration would have to address the availability of water to make navigation feasible
- There has been a significant reduction in the area of and species associated with river and wetland habitats (2a)
- The level of protection provided by, and the condition of, existing defences on the Witham Haven against flooding is being reduced by rising levels and bank erosion (5a)
- The standard of flood defence along the lower Witham and its tributaries do not meet target standards (5b)
- Standards of flood protection along the (i) Upper Witham at Grantham and (ii) the South Forty Foot Drain do not meet target standards
- Locally, inadequately maintained riparian drainage systems give rise to land drainage problems (5e)
- There is concern that development within the catchment may be contributing to increasing flood risk in Lincoln and Grantham (5g)

**Grimsby/Ancholme**

This draft LEAP was published in June 1999 and the priority actions with most relevance to climate change are:

- Groundwater abstraction from the “Northern Chalk” aquifer, at times, exceeds available resources (1a)
- There has been a significant reduction in the area of, and species associated with, river and wetland habitats (2a)
- Standards of flood protection on lengths of river systems do not meet target standards (5a)

**Louth Coastal**

This action plan was published in October 1998 and the priority actions with most relevance to climate change are:

- There is a limited understanding of the groundwater hydrogeology south of Louth (1)
- Changes in land drainage and agricultural practices have reduced habitat diversity and the landscape characters of rivers, their surrounding flood plains and the coastal marsh area (2a)
- There is a concern that abstraction from the Chalk aquifer is leading to depleted spring flows and there is limited understanding of the linkages between river flow regimes and water needs to sustain river life (2d)
- Salt water intrusion into East Coast streams can affect water quality (4e)
- The proposals by the Louth Navigation Trust to restore the Louth Navigation are constrained by water resource, water quality, flood defence and environmental concerns (4e)
- Flood protection provided to the coastal strip between Saltfleet Haven and North Coates Point may not meet Agency/MAFF standards (5a)
- The long term capability of Croft Lane Pumping Station, Wainfleet and the old Chapel St Leonards Pumping Station, to discharge flood waters, may not meet Agency standards (5b)
- The condition of a length of flood bank along the Waithe Beck may not meet Agency/MAFF standards (5c)
- Flood protection provided on the Woldgrift Drain may not meet Agency/MAFF (5d)
- A fuller understanding of coastal processes and their impact on sea defences is required to enable the further development of long term sustainable sea defence strategies (7a)

**The Wash**

This action plan was published in March 1998 and the priority actions with most relevance to climate change are:

- The siltation of the river outfalls into the Wash impedes:
    a) the discharge of flood water thereby increasing the risk of flooding; and
    b) the passage of boats and ships along the navigable channels (1)
- Existing flood defence standards are threatened as:
    a) The structural integrity of the flood defences is diminishing as they reach the end of their useful life; and
    b) Sea levels rise (2)
- The habitat diversity and associated wildlife of the Wash are at risk from human activities and rising sea levels (5)
- Holiday, recreational and associated development away from existing centres poses a threat to the undeveloped coast (15)

**The Nene**

This LEAP was published in June 1999 and the priority actions with most relevance to climate change are:

- Competing demands for water from the Nene during periods of low flow threaten the ecological needs of dependent river and wetland systems (1a)
- There is insufficient knowledge of the impact, during drought periods, of abstraction for public water supply on the Nene, Nene Washes and the Nene Estuary (1b)
- There is insufficient water available in summer to meet the needs of any future growth in the demand for spray irrigation from the area of the North Level Inland Drainage Board (IDB) that is fed from the Nene via the slacker at the Dog-in-a-Doublet (1c)
- There has been a significant reduction in the area of, and species associated with, river and wetland habitats (2a)
- Salinity in the South Holland Main Drain adversely affects fishery and spray irrigation uses (4h)
- There are concerns that the MAFF indicative flood defence standards for urban areas are not being met at certain locations in the catchment (5a)
- There is concern that development within the catchment has contributed to increasing flood risk (5b)
- Siltation along the tidal length of the River Nene has restricted the capability of the channel to discharge fluvial floods (5d)

**Welland**

This action plan was published in January 1998 and the priority actions with most relevance to climate change are:

- The standard of flood defence at certain locations falls below current target standards eg Market Harborough (present standard is 1 in 70 year event, aim is for a future protection standard of 1 in 100 year event) and a number of villages along the Glen (2)
- Siltation of river outfalls and tidal structures impact on flood defence standards and affect the navigational use of waterways in the catchment (Cross reference Wash LEAP Issue 1) (3)
- The area of natural wet fenland habitat in the catchment has been reduced to less than 1% of historic levels (Cross reference Wash LEAP Issue 6) (5)
- Land drainage and agricultural practices have significantly reduced habitat diversity within rivers and their flood plains (18)
- The demand for water from the lower Welland and Glen exceeds available river flows in dry summers (19)

- Concern has been raised over local derogation/over commitment of resources within the Southern Limestone aquifer (21)

## 3.5 Conclusions

The above sections describe some of the main social, economic and environmental (natural and human made) features of the Region. Some indication has been given of the potential impacts of climate change on these features. A more in depth analysis is given in Chapter 5 dealing with the potential climate change impacts in the Region.

Overall, a number of conclusions can be drawn from the above:

- There are a number of features in the Region that could be vulnerable to climate change and associated issues:
  - The Region's businesses will be subject to the energy tax from April 2001. Traditional, relatively energy intensive industries, could be particularly affected;
  - Physical features such as the coastline and estuaries could be subject to erosion from rising sea levels and sea surges;
  - Increased risk of flooding both coastal and inland. Appropriate responses will need to be considered eg restrictions on developments in the floodplains;
  - Changing agricultural patterns;
  - Water resources could be under pressure;
  - Exacerbation of social inequalities eg impacts on poorer rural and inner city areas and changes in employment patterns eg agriculture and tourism. These issues need to be explored further;
  - Biodiversity is already under severe pressure in the Region. Climate change could increase this pressure but this will depend on the nature of the response; and
  - Some sources of emissions of greenhouse gases in the Region eg transport (especially air) and domestic (due to increasing household numbers) seem set to rise.
- There are also a number of opportunities:
  - Warmer weather could result in increased tourism and visitors to the Region. This is an economic opportunity but it will need to be managed appropriately to reduce the adverse impacts eg increased erosion and traffic;
  - Development of cleaner technology and services that reduce greenhouse gas emissions such as renewable energy and actions that help to adapt to climate change;

- Expansion of woodland and forestry. The implications for water resources will have to be considered;
- Biodiversity could benefit depending on how we respond to the climate change challenge; and
- Different agricultural products.

• The Environment Agency, through its Local Environment Agency Plans (LEAPs), identifies specific environmental priorities for the Region's water catchments. Some of these priorities could be affected by climate change issues eg water resources, water quality, flooding, biodiversity and emissions from industrial processes.

## 3.6 References

Draft Regional Planning Guidance, East Midlands Regional Local Government Association, Nov 1999

East Midlands Development Agency (emda) economic development strategy "Prosperity through People", Supporting Analysis, July 1999

Viewpoints on the East Midlands Environment, Environment Agency et al, May 1999

East Midlands Local Environment Agency Action Plans (LEAPs)

"Sustainability and Biodiversity, Priorities for Action in the East Midlands" East Midlands Regional Biodiversity Forum, April 1999

England Rural Development Plan – East Midlands Region, 2000-2006, Ministry of Agriculture, Fisheries and Food (MAFF), Jan 2000.

# 4. Regional Climate Change Scenarios for the East Midlands

*Main Author: Dr RL Wilby, University of Derby*

This chapter begins with a summary (section 4.1) that is followed by more detailed sections (section 4.2 onwards) on climate change observations and future modellling.

## 4.1 Summary

### 4.1.1 Observed Trends in Environmental Parameters

Annual mean temperatures over Central England showed a warming trend of +0.6 °C between 1901 and 1998. Five of the ten warmest years of the 20th Century occurred in the 1990s: 1990, 1995, 1997, 1998 and 1999. The warming was greatest in the four months August–November with little or no warming trend in other months (excepting March).

Annual precipitation in Central and Eastern England increased slightly (+3%) since the 1930s despite reductions in both winter and summer rainfall totals (about –3% in each case). Although these changes are well within the range of inter–annual variability, individual months display significant trends. December totals increased by +38% and July totals fell by –38% over the same period. Since the 1960s there have also been a marked increase in summer dry-spell persistence and a reduction in the intensity of summer storms. There has been no long–term trend in the frequency of severe gales since 1881, but decadal average gale activity was greatest in the 1990s.

Annual potential evaporation rates in the Midlands have increased slightly (+3%) since the 1900s. Four of the ten years with highest evaporation losses have occurred since 1989, although there was also a notable decade of above average evaporation totals in the 1940s. Summer relative humidities have declined since the 1920s. Exceptionally low summer humidities in 1933/34, 1975/76 and 1989/90 were connected with widespread regional drought.

Summer runoff totals in the Rivers Dove and Manifold showed a decline since the 1950s and 1960s that has been partly offset by slight increases in winter flow. However, only the changes in the Manifold were significant when inter–annual variability was taken into account. Changes in the frequency of very high or very low flows were also within the limits of historic variability. Reconstructed "natural" flow series for the River Derwent suggest that droughts in 1887, 1858 and 1921 were more severe than those experienced in 1976 and 1995. Similarly, the decade of highest annual mean runoff in the Derwent occurred in the 19th rather than the 20th Century.

Observed rates of sea-level rise for the east coast of England between Whitby and Cromer range from +1.1 mm/year at Immingham to + 2.1 mm/year at Whitby. These raw estimates include natural rates of tectonically induced sea level rise resulting from post-glacial coastal subsidence which are estimated at between 0 and +1.0 mm/year.

Historically the East Midlands has experienced a variety of river and ground water quality problems including: surface water acidification, nutrient enrichment, and soil erosion. In some areas, deteriorating water quality has been linked to incremental land-use changes, modern agricultural practices and the unusual climate conditions of recent decades.

### 4.1.2 Future Climate Scenarios for the East Midlands from UKCIP98

The UKCIP98 scenarios present four alternative future climates named **'Low'**, **'Medium-low'**, **'Medium-high'** and **'High'**. The **Low** and **Medium-low** scenarios assume a relatively slow increase in future greenhouse gas concentrations (approximately 0.5% per annum), whereas the **Medium-high** and **High** scenarios assume a relatively rapid increase in future concentrations (approximately 1% per annum).

The climate warming ranges from +1.1 °C for the **Low** scenario to +3.2 °C for the **High** scenario by the 2080s. This compares with +0.6 °C for Central England during the period 1901 to 1999. The warming in the UKCIP98 scenarios for Eastern England is slightly greater in summer than winter until the 2050s. Thereafter the opposite applies.

Year-to-year variability in seasonal temperatures also changes in the future. Winter variability decreases, indicating that very cold winters become rarer. Conversely, summer variability increases, indicating that very hot summers occur more frequently. Under the **Medium-high** scenario the annual number of days with temperatures greater than 25°C in Derbyshire increases from about 2 to 7 by the 2050s, and from about 8 to 19 in Nottinghamshire. Conversely, the number of freezing winter nights decreases across the East Midlands with the individual sites showing a reduction in frost frequencies of about 50% by the 2050s.

Historic precipitation series exhibit considerable inter–annual and inter–decadal variability. For individual seasons, precipitation anomalies in Central and Eastern England may be as high as ± 60% of the long-term average. Such high levels of natural variability, present considerable challenges when ascertaining the significance of human-induced climate change to water resource management in the Region.

Annual precipitation over Eastern England increases in all four UKCIP98 scenarios, by between 1 and 2% by the 2050s. This change reflects increases in winter precipitation by 11%, and reductions of summer precipitation by –16% under the **Medium-high** scenario. Inter–annual variability in seasonal precipitation also changes by the 2050s, with increases in all seasons, ranging from +2% in spring to +36% in autumn. Future changes in the frequency of severe summer and winter gales are of practical insignificance.

Potential evaporation over Eastern England increases in all seasons except winter (which shows no change) under the **Medium-high** scenario. By the 2050s summer evaporation increases by 15%, and autumn evaporation by 29%. Annual evaporation increases by + 14% by the 2050s under the **Medium-high** scenario, compared with an observed rate of + 3% at Oxford since the 1900s.

Estimates of future sea-level rise vary between 13 cm to 74 cm of climate-induced sea-level rise around East Anglia by the 2050s. When taking into account current rates of coast subsidence, the net sea level rise for East Anglia under the **Medium-high** scenario increases from + 28 (climate-only) to + 37 cm (climate plus tectonics) by the 2050s.

### 4.1.3 Comparison of Regional Climate Change Scenarios

The low temporal and spatial resolution of the UKCIP98 scenarios limits the scope for detailed impact assessments at sub–regional scales. The climate of Eastern England is represented by a single Global Circulation Model (GCM) grid–box with an average elevation of 73 metres. To obtain climate change scenarios for the East Midlands at higher spatial resolutions requires the use of either a regional climate model (RCM) or statistical downscaling (SDS).

The East Midlands domain of the Hadley Centre's regional climate model (HadRM2) is represented by approximately 12 RCM grid–boxes with a spatial resolution of 50 km. The elevation range of these grid–boxes is 30 to 180 metres (compared with an absolute range in the Region of 0 to 636 metres). HadRM2 simulates the future climate for the period 2080–2100 given the boundary forcing of the HadCM2 GGa2 (greenhouse gas only) experiment (also the basis of the **Medium-high** UKCIP98 scenario).

The RCM shows more winter warming and larger seasonal precipitation changes than the GCM (HadCM2). Overall, the annual mean temperature change of the East Midlands domain is within 0.2°C and the annual mean precipitation change within 2% of the GCM changes, suggesting that the RCM and GCM responses to greenhouse gas forcing are broadly consistent for the Region.

The RCM shows a change in annual temperature of +3.0 °C by 2080–2100 for the East Midlands domain. However, this average conceals sub–regional variations in annual temperature changes that range from +2.8 °C in north Derbyshire and Lincolnshire, to +3.2 °C in south Leicestershire. The spatial variability for temperature change is greater in summer (standard deviation 0.19 °C) than in winter (0.10 °C).

Mean annual, winter and summer temperature changes are all negatively correlated with latitude confirming the existence of a north–south gradient (i.e., greater warming in the south). No systematic relationship was found between elevation and temperature change.

The RCM shows a change in annual precipitation of +7% by 2080–2100 for the East Midlands domain. However, this average conceals sub–regional variations in annual precipitation changes that range from +4% in south Leicestershire to +9% on the Lincolnshire coast. The spatial variability for precipitation change is greater in summer (standard deviation 4.8%) than winter (2.5%).

Mean annual and summer precipitation changes are positively correlated with latitude (indicating larger precipitation increases in the north of the Region and larger summer deficits in the south). Mean winter precipitation changes are negatively correlated with longitude, an index of distance from the coast (indicating larger winter precipitation increases in the west of the Region). No systematic relationship was found between elevation and precipitation change.

A statisitcal downscaling technique was used to generate future climate change scenarios for the Region. Statistical downscaling (SDS) is analagous to the "model output statistics" and "perfect prog" approaches used for short–range numerical weather prediction. SDS methods employ observed relationships between climate variables at the synoptic scale (such as surface pressure fields) and weather at the local scale (such as station precipitation). Future climate change scenarios are generated for the same locations by forcing these empirical relationships with the equivalent synoptic scale variables produced by a GCM.

A regression–based SDS method was used to downscale daily temperature and precipitation at five meteorological stations in the East Midlands (Buxton, Derbyshire; Cranwell, Lincolnshire; Raunds, Northamptonshire; Skegness, Lincolnshire; Sutton Bonington, Nottinghamshire). The future climate at each meteorological station was simulated for the period 2080–2099 given the boundary forcing of the HadCM2 GSa1 experiment (which combines the greenhouse–gas concentrations of GGa1 with negative forcing from sulphate aerosols).

Three sets of SDS scenarios were generated. SDS–1, employs three surface atmospheric circulation variables (zonal and meridional airflow strength, and vorticity) and one upper atmosphere predictor variable (500 hPa geopotential heights) supplied by HadCM2 for 1960–1989 and 2080–2099. SDS–2 and SDS–3, employ the same variables as SDS–1 for temperature, but the former uses surface specific humidity to downscale precipitation (occurrence and amounts), and the latter uses relative humidity to downscale precipitation occurrence. Thus, SDS–1 simulates local precipitation changes due to atmospheric circulation changes only; whereas SDS–2 and SDS–3 reflect circulation changes **and** atmospheric humidity changes.

The SDS–1 scenario shows temperature increases and precipitation reductions in all seasons and at all locations (i.e., a warmer, drier climate). Annual temperature changes range from +1.7°C (at Buxton, Skegness, and Sutton Bonington) to +1.9°C (at Raunds). Raunds also returns the largest winter mean (+1.1°C) and summer mean (+2.2°C) temperature changes, together with the smallest winter mean (–18%) and largest summer mean (–38%) reductions in precipitation. The largest reduction in winter mean precipitation occurs at Skegness (–22%), and the smallest change in the summer mean at Buxton (–22%).

The SDS–2 scenario shows precipitation increases in both seasons and at all locations (i.e., a warmer, wetter climate). Annual precipitation changes range from +4% (at Buxton) to +18% (at Cranwell). The same sites return the largest and smallest changes in winter precipitation (respectively +20% and +4%) and summer precipitation (respectively +6% and +23%). The SDS–2 scenario also suggests increased precipitation intensities for the heaviest storms and longer dry–spells between wet–days in summer. The SDS–1 and SDS–2 seasonal temperature changes are identical.

The SDS–3 scenario shows precipitation reductions smaller than those of SDS–1 in all seasons and at all locations (i.e., a warmer climate with relatively modest reductions in rainfall). Annual precipitation changes ranges from –1% (at Cranwell and Raunds) to –11% (at Skegness). Cranwell returns the smallest changes in winter and summer precipitation (–2% and –5% respectively). The largest reduction in winter and summer precipitation occurs at Skegness (–9% and –17% respectively).

SDS annual and summer temperature changes are negatively correlated with latitude, indicating a north–south gradient in the pattern of warming (i.e., greater warming in the south than in the north of the region). The only other significant (positive) correlation is between the mean annual precipitation change of SDS–1 and latitude, indicating greater reductions in precipitation in the south than in the north. As with the RCM, no systematic relationships were found between elevation and either downscaled temperature or precipitation change.

Differences amongst the SDS results highlight the sensitivity of statistically downscaled climate scenarios to the choice of predictor variables. Large rainfall reductions in SDS–1 scenario are a consequence of future increases in the thickness of the lower atmosphere, whereas the modest rainfall increases in SDS–2 are largely a consequence of future increases in specific humidity. SDS–3 yields precipitation changes intermediate to SDS–1 and SD–2 implying that future changes in atmospheric circulation have a greater bearing on future rainfall occurrence than changes in atmospheric relative humidity. Overall, the SDS–2 scenario is most consistent with the driving GCM scenario.

Several recommendations are made with respect to improving existing climate change scenarios for the East Midlands. Possible changes in other climate variables (such as wind speed, humidity, evaporation and solar radiation) should be considered alongside temperature and precipitation. Possible changes in the distributions of *daily* climate variables should be considered, as should changes in extreme events (such as gales, flooding, droughts, etc.). RCM and SDS scenarios should be used to drive hydrological and agricultural impact models to assess the significance of regional climate change relative to historic climate variability.

## 4.2 Observed Trends in Environmental Parameters

Numerous articles have reviewed recent climatic variability and/or potential climate change impacts from a UK perspective (see Table 10). For an introduction to the *average* (1961-90) climate of the English Midlands the interested reader is referred to Wheeler and Mayes (1997). Here, we provide an assessment of *trends* in mean temperature and precipitation that relate specifically to the East Midlands (i.e., Derbyshire, Leicestershire, Lincolnshire, Northamptonshire, Nottinghamshire, and Rutland). We identify (extreme) recent years that may serve as analogues for the future climate of the Region. We also analyse long-term trends in annual evaporation rates, river flow, sea level change and water quality at representative sites in and around the Region.

### 4.2.1 Historic Trends in Temperature

The UK Midlands Region contains the Central England Temperature (CET) series, the longest instrumental climate series in the world. The monthly record extends back to 1659 and presents a unique opportunity to examine climate variability in the Region over long time scales (Manley, 1953; 1974; Parker et al., 1992). Figure 3 shows the record of annual, winter and summer mean temperatures for the CET from 1901 to 1999. Annual mean temperatures showed a warming of +0.6 °C over this period, with six of the warmest years in the 20$^{th}$ Century occurring since 1989: 1999, 1990, 1997, 1995, 1989 and 1998. Relative to 1961-90 all these years were between 0.9 and 1.2 °C warmer than average. The warming has been greatest from mid-summer to late autumn: July (+ 0.8 °C), August (+ 1.2 °C), September (+ 0.9 °C), October (+ 1.2 °C) and November (+ 1.3 °C) respectively. With the exception of

March (+ 1.0 °C), the remaining months showed no statistically significant warming over the Century.

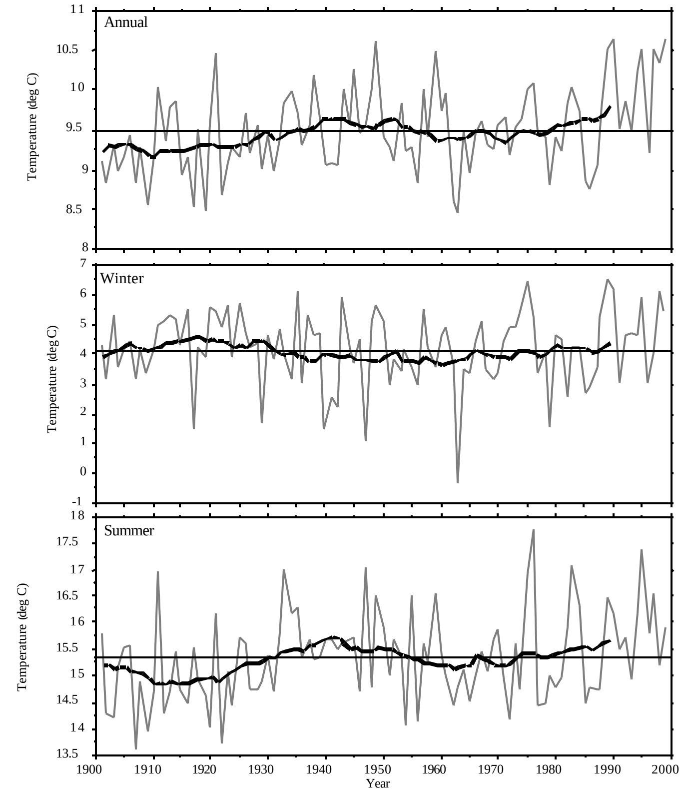



**Figure 3.** Annual, winter and summer mean temperatures (degrees C) for the Central England Temperature (CET) series 1901-1999. Smooth curves show 20-year moving averages and horizontal lines show the 1961-1990 average.

### 4.2.2 Historic Trends in Precipitation and Gales

Recent precipitation trends for the Region were analysed using area-average rainfall totals for Central and Eastern England (CEE) for the period 1931 to 1999 (Figure 4). The CEE data were obtained from the updated record of monthly rainfall totals for nine homogeneous regions in the UK (Gregory et al., 1991; Jones and Conway, 1997). Relative to the 1930s, annual precipitation increased slightly (+ 3%) over this period, even though both winter (–3%) and summer (–2%) showed slight declines. Individual months and years show far larger departures from the long-term average. For example, December rainfall totals have increased by + 38% since the 1930s, and July totals have fallen by -31% over the same period. The summers of 1995 and 1976 were the two driest since 1931, with seasonal totals respectively –68% and –62% below normal. Conversely, the two wettest winters were 1937/38 (+ 56%) and 1977/78 (+ 55%). Interestingly, the much celebrated wet winters of 1989/90 and 1994/95 (see Marsh and Monkhouse, 1993; Marsh and Turton, 1996) were ranked only 30$^{th}$ and 22$^{nd}$ wettest respectively for CEE. The lowest panel in Figure 4 shows the difference between winter and summer precipitation in the CEE Region. Although recent decades have witnessed a slight tendency towards drier winters than summers the overall trend was statistically insignificant.

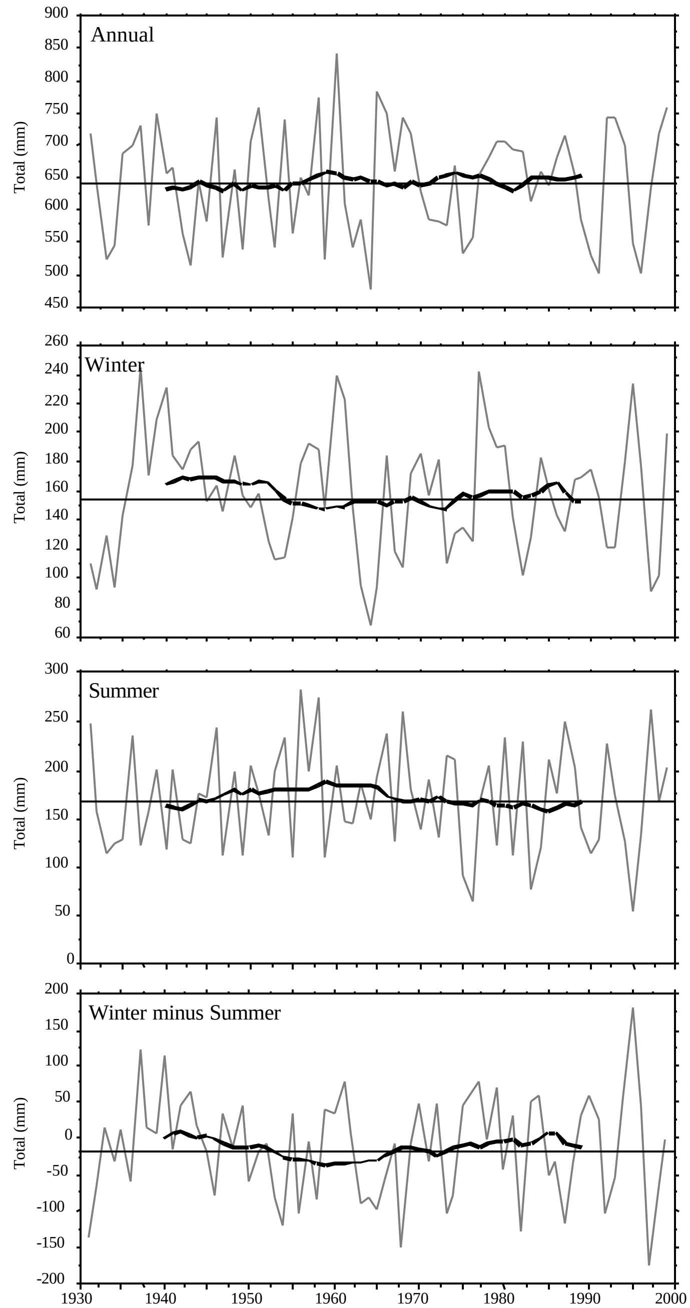



**Figure 4.** Annual, winter and summer precipitation totals (mm) for Central and Eastern England, 1931-1999. The bottom panel shows the difference between the winter and summer precipitation totals. Smooth curves show 20-year moving averages and horizontal lines show the 1961-1990 average.

Changes in daily precipitation occurrence and wet-day amounts are also relevant to many environmental processes (eg flooding, groundwater recharge, soil erosion, etc.). Since the 1960s there has been a slight reduction in the frequency of summer wet-days and an increase in dry-spell persistence, both of which have been attributed to large-scale, atmospheric circulation changes over the North Atlantic (Wilby et al., 2000). During the same period, heavy rainfall events contributed proportionately more to winter, spring and autumn precipitation totals than light or intermediate storms (Osborn et al., 2000). Conversely, summer rainfall totals are increasingly dominated by light and moderate precipitation events, leading to a slight reduction in mean intensities during this season.

Due to problems associated with site– and instrument–changes, long homogeneous records of gale activity are difficult to develop. Nonetheless, Jones et al. (1999) used adjusted grid–point mean–sea–level pressure data to calculate a simple index of gale activity over the UK for the period 1881–1997. This record shows no long–term trend, but the average frequency of severe gales did attain a maximum in the 1990s (corresponding to the pronounced westerly phase of the North Atlantic Oscillation during that decade).

### 4.2.3 Historic Trends in Evaporation and Humidity

A likely consequence of global warming will be higher rates of evaporation. The Radcliffe Meteorological Station, Oxford (the world's oldest weather station) has a continuous record of evaporation since 1815 (Burt and Shahgedanova, 1998). Although this site lies outside of the study Region it is thought to be generally representative of evaporation losses in central England. Figure 5 shows the record of annual potential evaporation (PET) at Oxford from 1901 to 1996. Relative to the 1900s, annual PET in the late 1980s and 1990s was + 3% higher, with four of the ten highest totals of the 20th Century (up to 1996) occurring in 1990, 1989, 1992 and 1995. With the exception of 1989 all of these years had annual PETs exceeding 500 mm. There was also a notable 9-year period of high PETs centred on the 1940s.

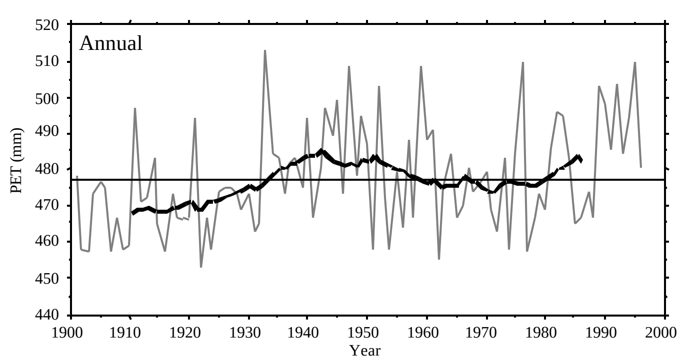



**Figure 5.** Annual totals of potential evaporation (mm) as estimated for the Radcliffe Meteorological Station, Oxford 1901-1999. The smooth curve shows 20-year moving averages and the horizontal line shows the 1961-1990 average.

Summer relative humidities have declined since the 1920s, with exceptionally low humidity values in August during the last two decades (Carter and Robertson, 1998). The Cranwell–Waddington relative humidity series indicates that occurrences of low humidities are becoming more frequent but not necessarily more intense (Lockwood, 2000). However, exceptionally low summer humidities in 1933/34, 1975/76 and 1989/90 were all connected with widespread regional drought.

### 4.2.4 Historic Trends in River Flow

Whilst climate change signals may be discernible from global and regional temperature data, detecting trends in river flow and 'peaks over threshold' series is far more problematic. This is because: most hydrological records tend to be short (<30 years duration); river flows are typically highly variable from year to year; wet– and dry–spells are sensitive to low-frequency climate forcing such as the North Atlantic Oscillation; land-use changes may amplify or conceal climate change signals; flow regulation, surface and groundwater abstraction mean that the flow regimes of most rivers are dominated by artificial influences. With these caveats in mind, the annual (Figure 6), winter and summer (Figure 7) mean flows for the Rivers Dove and Manifold were selected for trend analysis. Both catchments were considered to be relatively free of artificial influences throughout the period of available record. Furthermore, the River Dove is routinely used by the Institute of Hydrology to assess trends in low flow statistics.

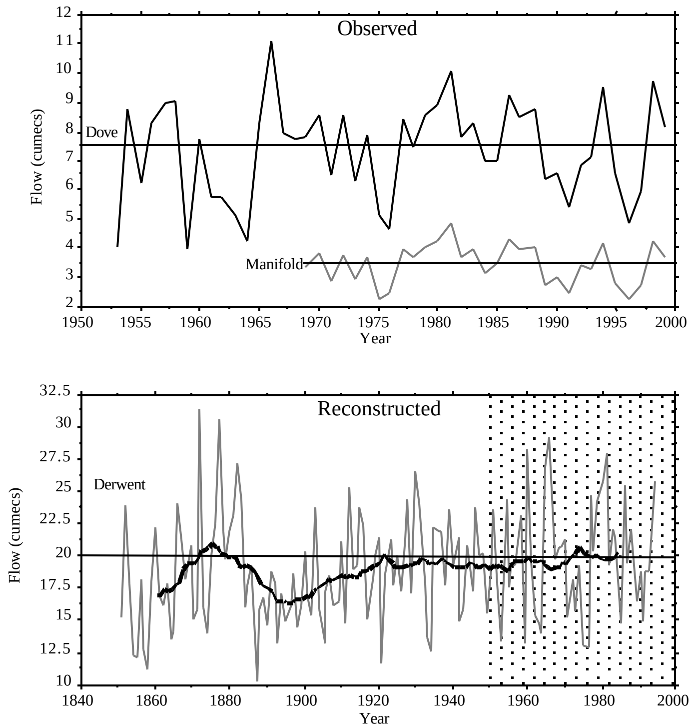



**Figure 6** . Upper panel: Observed annual mean flows in the River Dove at Rochester from 1954-1999, and River Manifold at Ilam from 1969-1999. Lower panel: Reconstructed annual mean flows in the River Derwent at St Mary's Bridge from 1851-1994 (Source: Jones and Lister , 1998). The smooth line shows the 20-year moving averages; the horizontal line shows the 1961-1990 average flow . The period of over-lapping observed and reconstructed records is identified by the stippled area.

Relative to the 1950s, annual runoff in the Dove has changed by + 7%, winter by +13% and summer by –30%.  The comparable statistics for the Manifold were –2% (annual), +<1% (winter), and –24% (summer).  However, when inter-annual variability is considered only the increased runoff in the Manifold for March/April and reduced flow in August/September, together with the summer decline, were statistically significant.  The lower panel of Figure 7 shows that the difference between winter and summer runoff increased in both rivers, but once again this change was not statistically significant.

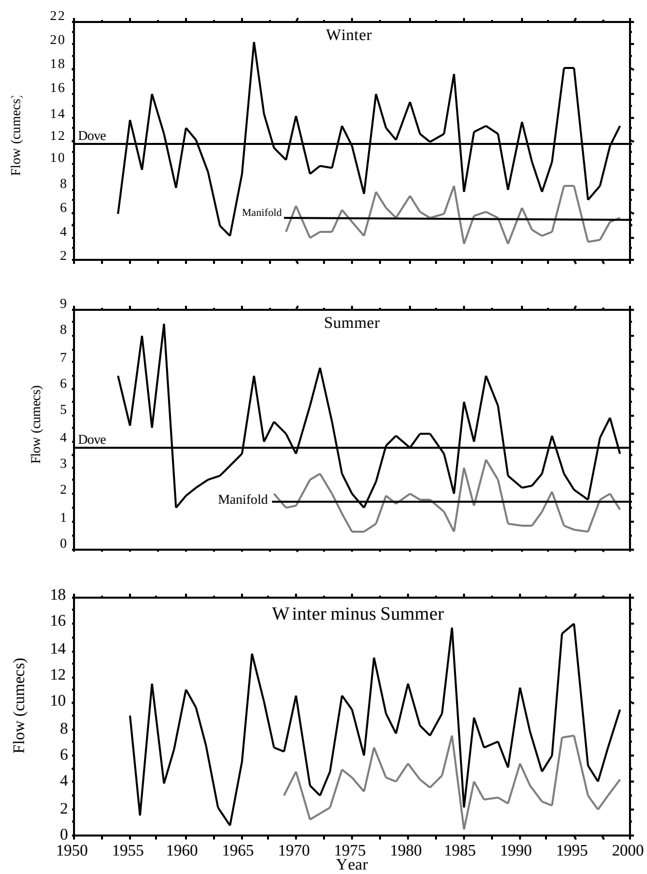



**Figure 7** Winter and summer mean flows in the Rivers Dove (1954-1999) and Manifold (1969-1999). The bottom panel shows the difference between the winter and summer flows. Horizontal lines show the 1961-1990 average.

The summers of 1996 and 1976 had the lowest flows on record for the Manifold (both –60% below normal), compared with 1976 (–62%), 1959 (–61%) and 1996 (–53%) for the Dove. Conversely, the winter of 1995/96 had the highest runoff in the Manifold (+51%), along with 1966/67 (+74%) and 1995/96 (+56%) in the Dove. These individual seasons also show up in the annual series of the frequency of days above or below the 10th and 95th percentiles for daily flow (Figure 8). However, there were no significant trends in the frequency of very high or very low flows in either river.

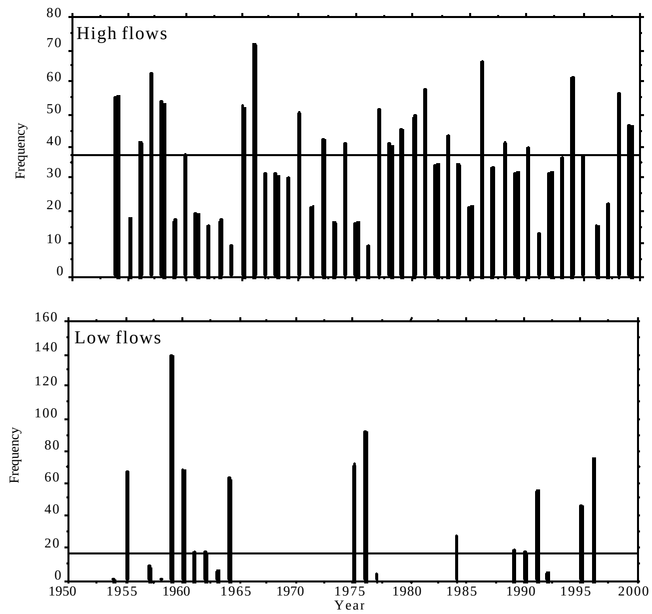



**Figure 8** Annual frequency of days exceeding the 10th percentile (high flows) or below the 95% percentile (low flows) in the River Dove 1954-1999. The expected annual frequencies in each case are shown by the horizontal line.

The lower panel in Figure 6 underlines the need to consider recent flow anomalies within a longer historical context. Reconstructed annual mean flow series for the River Derwent (Jones and Lister, 1998) for 1851-1995 show that the two most severe decades of drought predate the instrumental record: one in the 1850s, and the other between the mid 1880s and 1890s (see also Brugge, 1993). Three of the five most severe droughts occurred in the 1850s, with 1976 ranked only $8^{th}$. Conversely, the 1870s and early 1880s witnessed the years of highest mean annual runoff. If nothing else, the time series in Figure 6 highlights the need for caution when extrapolating trends in river flows from relatively short flow records.

### 4.2.5 Historic Trends in Sea Level

An anticipated consequence of global warming is a rise in mean sea-level, due to the thermal expansion of ocean water and the melting of land glaciers (Woodworth et al., 1999; Shennan, 1993). Since 1933, the Permanent Service for Mean Sea Level (PMSL) has been responsible for the collection, archiving, and analysis of sea level data from a global network of tide gauges (Woodworth, 1991). This data base currently holds records for over 50 stations around the British Isles, of which about a dozen have records that are at least 30-years in length. The majority of these sites show a rise in sea level over the last century, but rates vary from -1.1 mm/year (at Lerwick) to +3.0 mm/year (at Devonport) depending on regional variations in glacial unloading (see Shennan, 1989).

The closest tide gauge to the East Midlands is at Immingham, Humberside. Figure 9 shows the monthly mean sea-level at this station since 1960. Between 1960 and 1995 the combined effects of tectonic subsidence and thermal expansion of the ocean resulted in an average change in sea-level of +1.1 mm/year. This rate is close to the national average, but more rapid sea-level rise has been observed at neighbouring stations in Whitby (+2.1 mm/year) and Cromer (+1.8 mm/year).

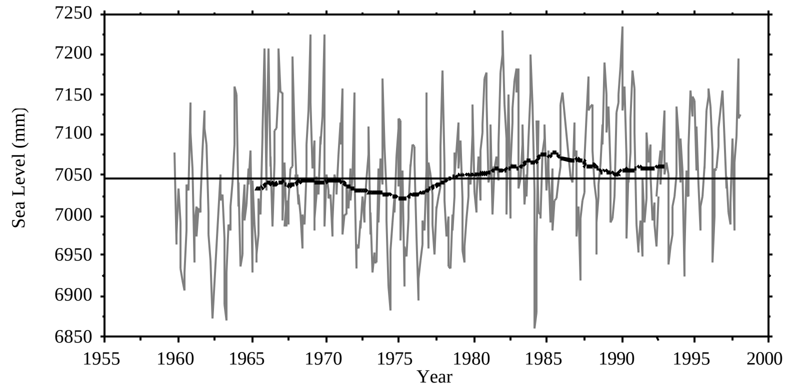



**Figure 9.** Monthly mean sea level at Immingham 1960-1997. The smooth line shows the 10-year moving averages; the horizontal line shows the 1961-1990 average sea level. Between 1960-1995 the average change in sea level was +11.1 mm/decade.

### 4.2.6 Historic Trends in Water Quality

Finally, it is appropriate to outline changes in other environmental variables that relate more specifically to the geography of the East Midlands. Historically the Region has experienced high rates of acid deposition from anthropogenic sources, but model experiments suggest that recent air pollution measures could result in the long-term recovery of acidified streams in Charnwood Forest, Leicestershire (Whitehead et al., 1993). However, there was evidence that this recovery slowed, or even reversed, during the alternating summer droughts and exceptionally wet winters of 1988 to 1990 (Wilby, 1994). Rising river water temperatures, particularly in low elevation and slow moving lengths (Webb, 1996) have also been linked to apparent declines in some fish populations (Hawley and Murphy, *pers. comm.*)

Incremental land-use changes associated with the National Forest may have long-term consequences for local micro-climates, groundwater recharge, and water quality (Wilby, 1998). Changes in land use, agricultural practices and fertiliser applications have been linked to systematic increases of nutrient concentrations (principally nitrate, phosphate and potassium) in the Region's major rivers and aquifers (José, 1989). Elsewhere, higher livestock densities, hedgerow removal and a transfer from pasture to arable cultivation, have contributed to higher rates of soil erosion and sediment delivery in recent decades (Foster, 1995).

## 4.3 Future Climate Scenarios for the East Midlands

Four sets of climate change scenario are presented: (1) the UKCIP98 scenarios for Eastern England (the grid-box most closely corresponding to the East Midlands); (2) analogue scenarios constructed from observed climate data which may resemble the future climate of the Region; (3) climate change scenarios produced by the Hadley Centre's regional climate model (HadRM2); and (4) statistically downscaled climate change scenarios for individual meteorological stations in the East Midlands. For an appraisal of the relative merits of each technique, the reader is referred to the reviews of Giorgi and Mearns (1991; 1999) and of Wilby and Wigley (1998).

### 4.3.1 UKCIP98 Scenarios

The UKCIP98 scenarios incorporate four plausible future climates termed **Low**', '**Medium-low**', '**Medium-high**', and '**High**'. The **Low** and **Medium-low** scenarios assume a relatively slow increase in future greenhouse gas concentrations (approximately 0.5% per annum), whereas the **Medium-high** and **High** scenarios assume a relatively rapid increase in future concentrations (approximately 1% per annum). As a point of reference, global greenhouse gas concentrations increased by 0.8% during the 1990s (Hulme and Jenkins, 1998). Note also, that the scenarios do **not** incorporate climate forcing due to sulphate aerosols. Therefore, given the large uncertainties in projecting future emissions (and hence radiative forcing), it is unwise to assign relative probabilities of occurrence to any of the four scenarios. Rather, the scenarios should be considered equally plausible for risk-assessment.

**Seasonal Temperatures**

Changes in mean annual, winter and summer temperatures in Eastern England for the **Medium-high** scenario are shown in Table 5. By the 2080s the warming ranges from +1.1 °C for the **Low** scenario to +3.2 °C for the **High** scenario. This compares with +0.6 °C for Central England during the period 1901 to 1999 (see above). The warming in the UKCIP98 scenarios for Eastern England is slightly greater in summer than winter until the 2050s. Thereafter the opposite applies. By the 2080s, the diurnal temperature range changes by –0.3 °C in winter, and by +0.l °C in summer. As Table 6 indicates year-to-year variability in seasonal temperatures also changes in the future. Winter variability decreases in all three periods, indicating that very cold winters become rarer. Conversely, summer variability increases, indicating that very hot summers occur more frequently.

**Table 5 Changes in mean annual, winter and summer temperatures (ºC) of Eastern England with respect to the 1961-90 mean for thirty-year periods centred on the 2020s, 2050s and 2080s, for the UKCIP98 Medium-high scenario.**

| Season | 2020s | 2050s | 2080s |
|---|---|---|---|
| Annual | +1.3 | +2.0 | +2.8 |
| Winter | +1.3 | +2.0 | +3.0 |
| Summer | +1.4 | +2.2 | +2.7 |

**Table 6 Changes in inter-annual variability (%) in mean annual, winter and summer temperatures of Eastern England with respect to the 1961-90 mean for thirty-year periods centred on the 2020s, 2050s and 2080s, for the UKCIP98** Medium-high **scenario. Changes are from pooled results of four HadCM2 experiments, and are calculated as the percent change in the standard deviation.**

| Season | 2020s | 2050s | 2080s |
|---|---|---|---|
| Annual | +5 | +19 | +10 |
| Winter | –3 | –12 | –14 |
| Summer | +11 | +38 | +34 |

## Daily Temperature Extremes

It is possible to make estimates of changing daily temperature extremes by applying the seasonal average changes of the UKCIP98 scenarios (Table 5) to the distributions of daily temperature at specific locations in the East Midlands (Buxton [Derbyshire]; Cranwell [Lincolnshire]; Raunds [Northamptonshire]; Skegness [Lincolnshire]; Sutton Bonington [Nottinghamshire]). The average number of 'hot' days (with maximum daily temperatures above 25 °C) increased at all five sites (Table 7). For example, under the **Medium-high** scenario the annual number of hot days at Buxton increases from about 2 to 7 by the 2050s, and from about 8 to 19 at Sutton Bonington.

**Table 7 Average annual number of days with maximum temperatures exceeding 25°C**

| Scenario | Buxton, Derbys. | Cranwell, Lincs. | Raunds, Northants. | Skegness, Lincs. | Sutton Bonington, Notts. |
|---|---|---|---|---|---|
| Mean 1961-90 climate | 2 | 8 | 12 | 3 | 8 |
| Hot summer (1995) | 20 | 34 | 37 | 8 | 36 |
| Mean 2050s climate (UKCIP scenarios) | | | | | |
| **Low** | 4 | 12 | 18 | 5 | 12 |
| **Medium-low** | 5 | 15 | 23 | 8 | 16 |
| **Medium-high** | 7 | 19 | 29 | 10 | 19 |
| **High** | 8 | 21 | 33 | 12 | 22 |

Conversely, the number of freezing winter nights decreases at all locations (Table 8) with the majority of sites showing a reduction in frost frequencies of about 50% by the 2050s. Individual extreme years greatly exceed the 2050s average figures for hot days but were close for freezing nights. For example, the exceptionally warm year of 1995 had 34 days at Cranwell with maximum temperatures above 25 °C, whereas the minimum temperature at Skegness fell below freezing on only 13 occasions in 1990. Clearly, individual warm summers and mild winters in the 2050s may result in a greater number of hot days and fewer freezing nights than suggested by the decadal averages shown in Tables 9 and 10.

**Table 8 Average annual number of days with minimum temperatures below 0°C**

| Scenario | Buxton, Derbys. | Cranwell, Lincs. | Raunds, Northants. | Skegness, Lincs. | Sutton Bonington, Notts. |
|---|---|---|---|---|---|
| Mean 1961-90 climate | 66 | 56 | 59 | 33 | 53 |
| Mild winter (1989/90) | 35 | 29 | 33 | 13 | 29 |
| Mean 2050s climate (UKCIP scenarios) | | | | | |
| **Low** | 51 | 40 | 44 | 23 | 40 |
| **Medium-low** | 40 | 30 | 35 | 16 | 32 |
| **Medium-high** | 32 | 25 | 28 | 11 | 26 |
| **High** | 28 | 22 | 24 | 10 | 23 |

## Precipitation and Gales

It was noted above that historic precipitation series exhibit marked inter–annual and inter–decadal variability. For individual seasons, precipitation anomalies in Central and Eastern

England (CEE) may be as high as ± 60% of the long-term average. High levels of natural variability, therefore, present considerable challenges when ascertaining the significance of human-induced climate change to water resource management in the Region.

Annual precipitation over Eastern England increases in all four UKCIP98 scenarios, by between 1 and 2% by the 2050s (with respect to the 1961-90 average). As Table 9 shows, this change arises from increases in winter precipitation by 11%, and from reductions of summer precipitation by –16% under the **Medium-high** scenario by the 2050s. Table 10 shows that inter–annual variability in seasonal precipitation also changes by the 2050s, with increases in all seasons, ranging from +2% in spring to +36% in autumn (not shown).

**Table 9** **Changes in mean annual, winter and summer precipitation (%) of Eastern England with respect to the 1961-90 mean for thirty-year periods centred on the 2020s, 2050s and 2080s, for the UKCIP98 Medium-high scenario.**

| Season | 2020s | 2050s | 2080s |
|---|---|---|---|
| Annual | +3 | +1 | +5 |
| Winter | +7 | +11 | +19 |
| Summer | –3 | –16 | –16 |

**Table 10** **Changes in inter-annual variability in mean annual, winter and summer precipitation of Eastern England with respect to the 1961-90 mean for thirty-year periods centred on the 2020s, 2050s and 2080s, for the UKCIP98 Medium-high scenario. Changes are from pooled results of four HadCM2 experiments, and are calculated as the percent change in the standard deviation.**

| Season | 2020s | 2050s | 2080s |
|---|---|---|---|
| Annual | +6 | +16 | +11 |
| Winter | -4 | +8 | +19 |
| Summer | +11 | +3 | –2 |

As with the temperature data, it is possible to estimate future precipitation totals by applying the seasonal changes of the UKCIP98 scenarios to rainfall series at the same meteorological stations. Tables 11 and 12 indicate that the unusually wet winter of 1989/90 and the dry summer of 1995 were both more extreme than the respective average winter and summer conditions of the **High** scenario in the 2050s. However, all four UKCIP98 scenarios are suggestive of drier summers and wetter winters than the 1961-90 average, a change that is consistent only with observed trends in summer rainfall.

**Table 11 Average winter precipitation totals (mm)**

| Scenario | Buxton, Derbys. | Cranwell, Lincs. | Raunds, Northants. | Skegness, Lincs. | Sutton Bonington, Notts. |
|---|---|---|---|---|---|
| Mean 1961-90 climate | 373 | 135 | 145 | 145 | 155 |
| Wet winter (1989/90) | 462 | 211 | 229 | 193 | 261 |
| Mean 2050s climate | | | | | |
| **Low** | 396 | 143 | 154 | 153 | 164 |
| **Medium-low** | 411 | 148 | 160 | 159 | 171 |
| **Medium-high** | 414 | 150 | 161 | 160 | 172 |
| **High** | 422 | 152 | 164 | 163 | 175 |

**Table 12 Average summer precipitation totals (mm)**

| Scenario | Buxton, Derbys. | Cranwell, Lincs. | Raunds, Northants. | Skegness, Lincs. | Sutton Bonington, Notts. |
|---|---|---|---|---|---|
| Mean 1961-90 climate | 274 | 164 | 151 | 154 | 172 |
| Dry summer (1995) | 130 | 35 | (41) | 52 | 28 |
| Mean 2050s climate | | | | | |
| **Low** | 263 | 157 | 145 | 147 | 165 |
| **Medium-low** | 254 | 152 | 140 | 143 | 160 |
| **Medium-high** | 230 | 138 | 127 | 129 | 144 |
| **High** | 224 | 134 | 124 | 126 | 141 |

Annual severe gale frequencies over the British Isles decline in both winter (–10%) and summer (–16%) by the 2050s under the **Medium-high** scenario. However, due to the high inter–annual and inter–decadal variability of the gale index it is difficult to distinguish a clear anthropogenic signal in gale frequencies from the noise of natural climate variability. Furthermore, severe gales are very rare (less than 2 per year) in both winter and summer, making the above frequency changes of practical insignificance. This conclusion is also supported by GCM derived estimates of gale frequencies based on the strength of geostrophic flow and vorticity which show no increase in either quantity over Europe associated with projected increases in greenhouse gases (Conway and Jones, 1998).

## Evaporation

Potential evaporation (PET) over Eastern England increases in all seasons except winter (which shows no change) under the **Medium-high** scenario. By the 2050s summer PET increases by 15%, and autumn evaporation by 29%. Annual PET increases by + 14% by the

2050s under the **Medium-high** scenario, compared with an observed rate of + 3% at Oxford since the 1900s.

**Sea-level change, saline ingress and coastal flooding**

The UKCIP98 scenarios provide estimates of future global-mean sea-level rise. These estimates range from +13 to +74 cm for climate-induced sea-level rise around East Anglia by the 2050s. When taking into account current rates of coastal subsidence, the net sea level rise for East Anglia under the **Medium-high** scenario increases from + 28 (climate-only) to + 37 cm (climate plus tectonics) by the 2050s. Higher sea levels imply greater risk of saline ingress to river networks and coastal aquifers such as the south Lincolnshire limestone. Elevated salinity concentrations can cause fish mortality or favour the growth of nuisance algae (such as prymelium) that release fish toxins (Hawley, *pers. comm.*).

The future risk of coastal flooding depends upon the changing nature of storm surges (or storminess) in relation to mean sea-level. Hulme and Jenkins (1998) suggest that high-tide levels at Harwich with a current return period of 100 years could recur every 10 years by the 2050s assuming a rise in mean sea-level of 25 cm even without a change in storminess. Similarly, Hulme (*pers. comm.*) reports that a rise of 50 cm in mean sea-level at Immingham (expected by the 2090s under the **Medium-high** scenario) would convert the one in 500 year storm surge to a once in 30 year event. Taking into account changes in storminess the 1–in–500 year storm surge at Immingham increases from 1.9 m to 2.7 m.

### 4.3.2 Climate Change Analogues

Climate change analogues are constructed by identifying climate records that may typify the future climate of a given Region. The analogue can be obtained from either past climate data (temporal analogue) or from another Region (spatial analogue). A major advantage of the analogue approach is that the future climate scenario (and associated impacts) may be described at far greater temporal and spatial resolutions than might otherwise be possible (eg Subak et al., 2000). For example, the hot/dry summers of 1976 and 1995, and the mild/wet winters of 1990/91 and 1994/95 may provide useful temporal analogues for future climate change in the East Midlands. Accordingly, the following paragraphs provide a brief illustration of the analogue method.

The summer of 1995 was the third warmest recorded in the CET series since 1659 with a mean temperature anomaly of + 2.0 °C above the 1961-90 average. However, the summer warmth of 1995 approximates the *average* summer temperature expected for Eastern England by the 2050s under the **Medium-high** scenario. As Table 7 indicates, the summer of 1995 also experienced an exceptionally large number of days with maximum temperatures exceeding 25 °C. Frequencies of such hot days at the chosen locations were between three and ten times higher than the 1961-90 average. Comparable frequencies are approached (but not exceeded) under the UKCIP98 scenarios for the 2050s. The summer of 1995 was also the driest in the Central and Eastern England (CEE) record since 1931 with just 32% of the normal rainfall total falling. However, the summer rainfall deficit of 1995 was more extreme than any *30–year average* scenario expected under any UKCIP98 scenario for Eastern England. In other words, the drought of summer 1995 was more severe than *normal* conditions expected by the 2050s. However, given the summer rainfall reductions reported in Table 9, the *likelihood* of individual summers being as dry as 1995 increases by the 2050s.

The same analogue approach may be applied to the mild/wet winters of 1989/90 (see Table 11) and 1994/95. The latter was the fourth wettest in the CEE record since 1931, with 154% of the 1961-90 average precipitation, and a temperature anomaly of + 1.8 °C. The mildness of 1994/95 approaches the *average* winter warmth expected for Eastern England by the 2050s under the **Medium-high** scenario. Such mild winters imply a reduced frequency of nights when the air temperature falls below 0°C. For example, during the 1994/95 winter, Cranwell and Skegness experienced 37 and 15 frosts respectively, compared to an average of 56 and 33 respectively. The wetness of 1994/95 was, however, greater than *average* conditions expected by the 2050s and 2080s under any UKCIP98 scenario for Eastern England. Nonetheless, the winter rainfall increases reported in Table 10, suggest that the *likelihood* of individual winters being as wet as 1994/95 increases by the 2050s and 2080s.

### 4.3.3 Regional Climate Model Scenario

The following paragraphs report preliminary analyses of output from the Hadley Centre's climate change experiments undertaken using the regional climate model (RCM) HadRM2. This model simulates the future climate for the period 2080–2100 given the boundary forcing of the HadCM2 GGa2 (greenhouse gas only) experiment (also the basis of the **Medium-high** UKCIP98 scenario). Whereas one HadCM2 cell has an area of 70,000 $km^2$ at the latitude of the East Midlands, HadRM2 has a spatial resolution of 50 km (or cell size of 2500 $km^2$). This allows the East Midlands to be represented approximately by 12 land grid cells with a model elevation range of 30 to 180 metres above mean sea level (Figure 12). Although HadRM2 elevation range is still less than the absolute elevation range in the East Midlands (sea–level to 636 metres at Kinder Scout), it is superior to the single HadCM2 elevation of 73 metres. Furthermore, finer spatial and vertical scales enable the RCM to resolve important atmospheric processes (such as orographic precipitation) better than the driving GCM (Jones et al., 1995; Murphy, 1999).

**Seasonal Temperature and Precipitation**

Table 13 shows the mean seasonal changes in temperature (°C) and precipitation (%) by 2080–2100 with respect to 1961–90 for the UKCIP98 **Medium-high** scenario for the Eastern England domain of the GCM (HadCM2) and the RCM (HadRM2). For the purpose of comparison, the mean climate changes of grid–points representing land–only, and just the East Midlands Region, are also shown. The full domain response of the RCM is slightly different from the GCM: more winter warming and larger seasonal precipitation changes. These differences are even more pronounced in the land–only response of the RCM because the 7 ocean grid–points included in the full RCM domain warm less rapidly than land grid–points and precipitation changes are generally smaller over the ocean. The East Midlands domain of the RCM also has more winter warming and larger seasonal precipitation changes than the GCM. Overall, the annual mean temperature of the East Midlands domain is within 0.2°C and the annual mean precipitation change within 2% of the GCM changes, suggesting that the RCM and GCM responses to greenhouse forcing are within the limits of internal model variability over the Region.

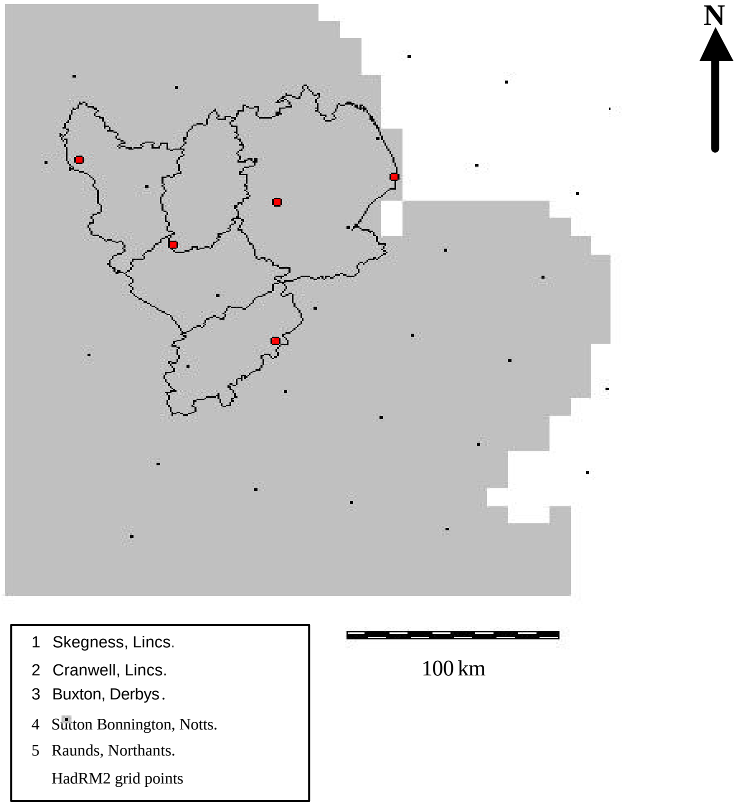



**Figure 12** Base map of the Region and statistical downscaling sites.

**Table 13** **Mean seasonal changes in temperature (ºC) and precipitation (%) by 2080–2100 with respect to 1961–90 for the UKCIP98 Medium-high scenario for the 'Eastern England' domain of the GCM (HadCM2) and the RCM (HadRM2). For comparison, land–only and East Midlands only grid–point changes are also shown. Note that one HadRM2 grid–point was included from the 'Welsh' domain of HadCM2 to provide coverage of north–west Derbyshire.**

| Variable | GCM, East England | RCM, Full Domain | RCM, Land–only | RCM, East Midlands |
|---|---|---|---|---|
| **Temperature (ºC)** | | | | |
| Annual | +2.8 | +2.9 | +3.1 | +3.0 |
| Winter | +3.0 | +3.4 | +3.5 | +3.5 |
| Summer | +2.7 | +2.6 | +2.8 | +2.6 |
| **Precipitation (%)** | | | | |
| Annual | +5 | +8 | +6 | +7 |
| Winter | +19 | +27 | +28 | +27 |
| Summer | –16 | –21 | –27 | –26 |

However, the gross averages shown in Table 13 conceal sub–regional variations in the RCM responses for seasonal precipitation and temperature. Figure 11 shows changes in mean annual, winter and summer climate over Eastern England for 2080–2100 relative to 1961–90, interpolated to 10 km resolution from HadRM2 grid–points. The change in annual temperature ranges from +2.8°C (in north Derbyshire and Lincolnshire) to +3.2°C (in south Leicestershire). Similarly, the change in annual precipitation ranges from +9% (on the Lincolnshire coast) to +4% (in southern Leicestershire). As the standard deviations in Table 14 reveal, the sub–regional variability is greater in summer than winter for both temperature and precipitation changes. Summer temperature changes show a north–south gradient across the Region ranging from +2.3°C in Derbyshire to +2.9°C in Leicestershire. In comparison, summer rainfall changes show a northeast–southwest gradient, ranging from –15% on the Lincolnshire coast to –33% in southwest Leicestershire.

**Table 14 Spatial variability (range and standard deviation) of the mean seasonal changes in temperature (ºC) and precipitation (%) by 2080–2100 with respect to 1961–90 for the 12 HadRM2 grid–points representing the East Midlands.**

| Variable | Maximum Change | Minimum Change | Standard Deviation |
|---|---|---|---|
| **Temperature (°C)** | | | |
| Annual | +3.2 | +2.8 | 0.10 |
| Winter | +3.7 | +3.3 | 0.10 |
| Summer | +2.9 | +2.3 | 0.19 |
| **Precipitation (%)** | | | |
| Annual | +9.1 | +4.4 | 1.56 |
| Winter | +31.7 | +23.5 | 2.50 |
| Summer | –32.7 | –15.2 | 4.83 |

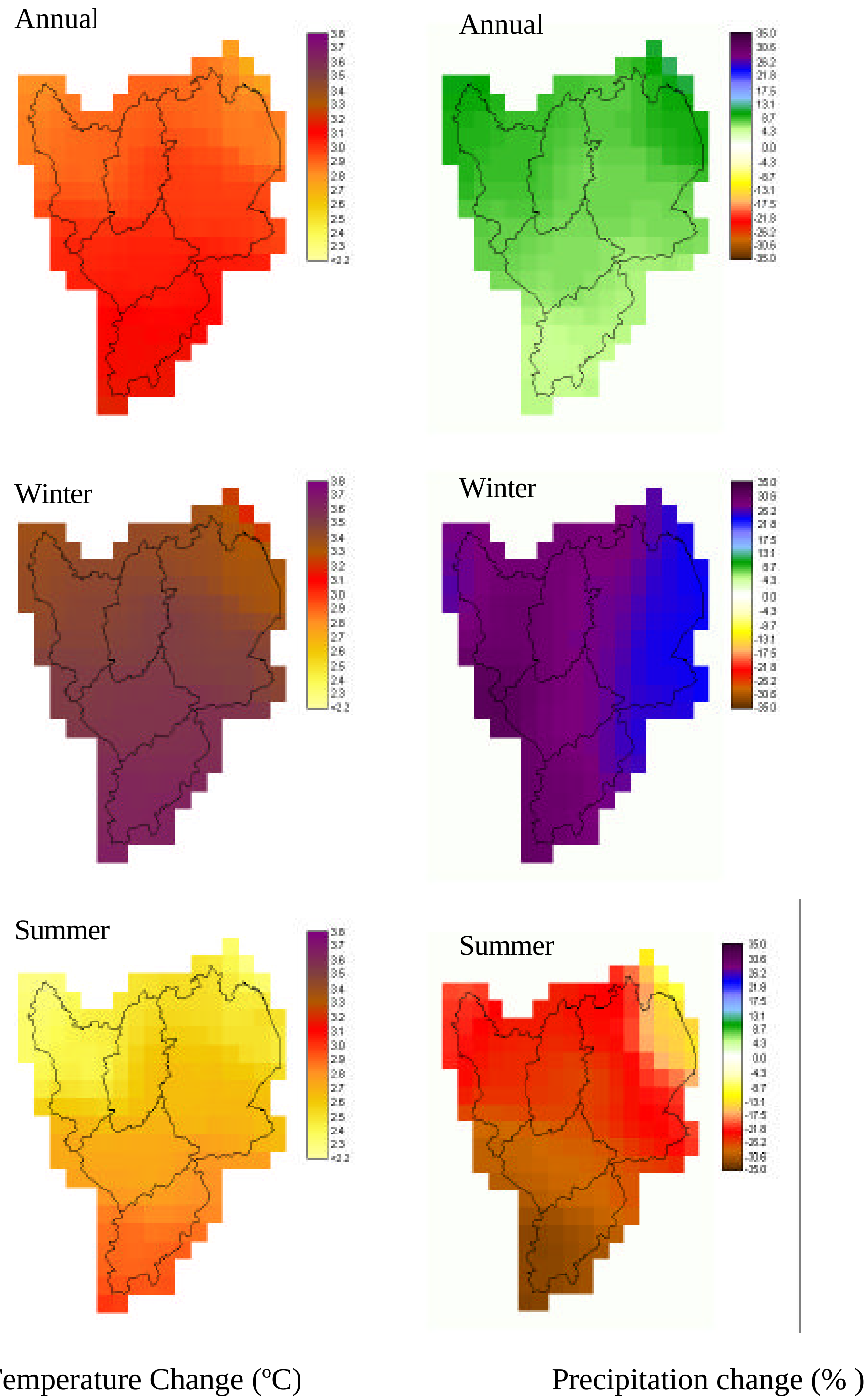



**Figure 11** Change in mean annual, winter and summer climate over the East Midlands* by 2080-2100 relative to 1961-90 for the HadRM2 scenario interpolated to a 10km grid: temperature (left panel); precipitation (right panel).

*** UK Government Census Standard Region valid until April 2001**

**Spatial Variability**

The underlying causes of spatial gradients in climate variables were investigated by correlating HadRM2 grid–point temperature and precipitation changes with corresponding grid–point elevations, latitudes and longitudes. Mean annual, winter and summer temperature changes are all negatively correlated with latitude confirming the pronounced north–south gradient (i.e., greater warming in the south). Conversely, mean annual and summer precipitation changes are positively correlated with latitude (i.e., indicating larger precipitation increases in the north of the Region and larger summer deficits in the south). Mean winter precipitation changes are negatively correlated with longitude, an index of distance from the coast (i.e., indicating larger winter precipitation increases in the west of the Region). No systematic relationships were found between elevation and either temperature or precipitation change, supporting the view that the pattern of climate change across the East Midlands is not differentiated by elevation.

In summary, the HadRM2 scenario suggests that winter temperature and precipitation increases will be greater in the south and west of the East Midlands than in the north and east (Figure 11). Summer temperature increases and rainfall reductions are also greater in the south than in the north of the Region. In both seasons, proximity to the coast tends to reduce seasonal precipitation changes. However, regional variations in climate change inferred from individual RCM grid–points should be interpreted with caution due to natural climate variability (which can be as high as ±0.4°C for temperature and ±7% for precipitation observations [New, 1999]), and due to random noise in the model output. It should also be noted that the HadRM2 experiment did not include sulphate aerosol forcing. This may introduce an additional signature to the spatial pattern of the regional climate change signal.

### 4.3.4 Statistically Downscaled Scenarios

Statistical downscaling (SDS) is analagous to the “model output statistics” and “perfect prog” approaches used for short–range numerical weather prediction (Klein and Glahn, 1974). Both applications employ observed relationships between climate variables at the synoptic scale (such as surface pressure fields) and weather at the local scale (such as single site precipitation and surface temperature). Future climate change scenarios are generated for the same locations by forcing these empirical relationships with the equivalent synoptic scale variables produced by a GCM. Common procedures for linking synoptic and local scale variables include weather-type classification, linear and non-linear regression, or modifications to stochastic weather generators (see Wilby and Wigley, 1997). Thus, SDS techniques are not computationally demanding and require orders of magnitude *less* computer time than RCMs to compute equivalent scenarios. However, SDS scenarios are highly dependent on the stability of the predictor–predict and relationship(s), and on the choice of predictor variable(s) used for downscaling future climate change (see Winkler et al., 1997).

The following paragraphs describe results obtained from a regression–based SDS method (discussed in detail by Wilby et al., 1999, and evaluated from an impacts perspective by Wilby et al., 2000). Three sets of scenarios are described for the five meteorological stations shown in Figure 12. The first, SDS–1, employs three surface atmospheric circulation variables (zonal and meridional airflow strength, and vorticity) and one upper atmosphere predictor variable (500 hPa geopotential heights, an index of the thickness of the atmosphere) to downscale daily temperature and precipitation. The second, SDS–2, employs the same variables as SDS–1 for temperature, but also includes surface specific humidity for precipitation downscaling. The third, SDS–3, also employs the SDS–1 variables for temperature, but uses relative humidity to downscale precipitation *occurrence* and specific humidity to downscale precipitation *amounts* (see Buishand and Beckmann, 2000; Charles et al., 1999).

The future climate at each meteorological station was simulated for the period 2080–2099 given the boundary forcing of the HadCM2 GSa1 experiment (which combines the greenhouse–gas concentrations of GGa1 with negative forcing from sulphate aerosols). This means that the SDS–1, SDS–2 and SDS–3 scenarios are not directly comparable to the HadRM2 results which originate from the greenhouse–gas–only boundary forcing of the HadCM2 GGa2 experiment. Unfortunately, the choice of HadCM2 GSa1 experiment was dictated by the availability of *daily* predictor variables for the downscaling (in particular, the humidity and upper atmosphere variables).

### Seasonal Temperature and Precipitation

Table 15 shows the mean seasonal changes in temperature (°C) and precipitation (%) by 2080–2099 with respect to 1960–89 for the atmospheric circulation change SDS–1 scenario at the five chosen sites in the East Midlands (noting that the 1960–89 means were also derived for SDS–1 to ensure internal consistency). The atmospheric circulation change (SDS–1) scenario suggests temperature increases and precipitation reductions in all seasons and at all locations. The change in annual temperature ranges from +1.7°C (at Buxton, Skegness and Sutton Bonington) to +1.9°C (at Raunds). Similarly, the change in annual precipitation ranges from –25% (at Raunds) to –17% (at Skegness). Raunds also returns the largest winter mean (+1.1°C) and summer mean (+2.2°C) temperature changes, together with the smallest winter mean (–18%) and largest summer mean (–38%) reductions in precipitation. The largest reduction in winter mean precipitation occurs at Skegness (–22%), and the smallest change in the summer mean at Buxton (–22%).

**Table 15 Statistically downscaled changes in mean annual, winter and summer temperature (ºC) and precipitation (%) for 2080–2099 at selected sites in the East Midlands with respect to 1960–1989 means. The results were produced using only changes in atmospheric circulation (scenario SDS–1).**

| Site | Elevation (metres) | Temperature change (ºC) | | | Precipitation change (%) | | |
|---|---|---|---|---|---|---|---|
| | | Annual | Winter (DJF) | Summer (JJA) | Annual | Winter | Summer |
| Buxton | 307 | +1.7 | +1.0 | +1.8 | –19 | –18 | –22 |
| Cranwell | 62 | +1.8 | +0.9 | +1.9 | –19 | –20 | –26 |
| Raunds | 59 | +1.9 | +1.1 | +2.2 | –25 | –18 | –38 |
| Skegness | 6 | +1.7 | +0.9 | +1.7 | –17 | –22 | –31 |
| Sutton B. | 48 | +1.7 | +0.9 | +1.9 | –21 | –21 | –34 |

Table 16 shows the seasonal changes in mean precipitation (%) by 2080–2099 with respect to 1960–89 for the SDS–2 and SDS–3 scenarios at the same sites (noting that the SDS–2 and SDS–3 seasonal temperature changes are identical to SDS–1). Contrary to the SDS–1 scenario, the atmospheric circulation and specific humidity change scenario (SDS–2) suggests precipitation increases in both seasons and at all locations. The change in annual precipitation ranges from +4% (at Buxton) to +18% (at Cranwell). The same sites return the largest and smallest changes in winter precipitation (respectively +20% and +4%) and summer precipitation (respectively +6% and +23%).

**Table 16** **Statistically downscaled changes in mean annual, winter and summer precipitation (%) for 2080–2099 at selected sites in the East Midlands with respect to 1960–1989 means. The results were produced using changes in atmospheric humidity and atmospheric circulation (scenarios SDS–2 and SDS–3). Note that the temperature changes are the same as SDS–1 (see above).**

| Site | Elevation (metres) | SDS–2 Precipitation change (%) | | | SDS–3 Precipitation change (%) | | |
|---|---|---|---|---|---|---|---|
| | | Annual | Winter | Summer | Annual | Winter | Summer |
| Buxton | 307 | +4 | +4 | +6 | –7 | –7 | –9 |
| Cranwell | 62 | +18 | +20 | +23 | –1 | –2 | –5 |
| Raunds | 59 | +15 | +11 | +20 | –1 | –4 | –7 |
| Skegness | 6 | +7 | +11 | +9 | –11 | –9 | –17 |
| Sutton B. | 48 | +12 | +11 | +6 | –4 | –2 | –16 |

The results for SDS–3 indicate that the downscaled precipitation scenario is not only sensitive to the inclusion of humidity as a predictor variable (i.e., comparing SDS–2 with SDS–1) but also to the type of humidity variable (i.e., comparing SDS–3 with SDS–2). The differences between SDS–2 and SDS–3 are due entirely to precipitation occurrence since both scenarios downscaled wet–day amounts using specific humidity. It is evident that the use of relative humidity (SDS–3), as opposed to specific humidity (SDS–2), results in fewer rain–days by 2080–2099 leading to a net reduction in annual and seasonal precipitation totals at all sites. Under SDS–3, reductions in precipitation totals are greater in summer than winter, and overall most pronounced at Skegness.

**Daily Temperature and Precipitation Extremes**

Table 17 shows the change in the average number of days with maximum temperatures above 25 °C between 2080–99 and 1960–89 according to the SDS–2 scenario. All five sites show an increase in the frequency of 'hot' days, but the greatest change was in the south of the Region (Raunds) and the smallest in the north (Buxton). Conversely, the greatest reduction in the average number of days with minimum temperatures below 0 °C occurred at Buxton where the annual frost frequency decreased from 69 days per year in 1960–89 to 43 days per year in 2080–2099.

**Table 17 Changes in the average annual number of days with maximum temperatures exceeding 25ºC, minimum temperatures below 0ºC, percentage changes in the seasonal intensity of heavy precipitation days, and percentage changes in the frequency of wet-days (defined as days with non–zero precipitation totals). All statistics were derived for 2080–2099 relative to 1960–89 using the SDS–2 scenario.**

| Extreme variable | Buxton, Derbys. | Cranwell, Lincs. | Raunds, Northants. | Skegness, Lincs. | Sutton Bonington, Notts |
|---|---|---|---|---|---|
| Temperature extremes (days/yr) | | | | | |
| Tmax > 25ºC | +2 | +13 | +18 | +7 | +12 |
| Tmin < 0ºC | –26 | –19 | –20 | –16 | –18 |
| Heavy precipitation (% change) | | | | | |
| Winter | –4 | +6 | +4 | –6 | –1 |
| Spring | +15 | +8 | +21 | +8 | +6 |
| Summer | +6 | +48 | +32 | +5 | –3 |
| Autumn | –3 | +11 | +12 | +1 | +27 |
| Wet-day occurrence (% change, SDS–2) | | | | | |
| Winter | +10 | +5 | +4 | +10 | +6 |
| Spring | +4 | +5 | +5 | +9 | +8 |
| Summer | –3 | –5 | –13 | –3 | –6 |
| Autumn | –9 | –11 | –13 | –16 | –8 |
| Wet-day occurrence (% change, SDS–3) | | | | | |
| Winter | –7 | –8 | –10 | –12 | –9 |
| Spring | –5 | –5 | –5 | –6 | –4 |
| Summer | –17 | –25 | –28 | –26 | –24 |
| Autumn | –17 | –24 | –24 | –28 | –22 |

Table 17 also shows the percentage change in the seasonal intensity of heavy precipitation days by 2080–2099 under the SDS–2 scenario. Here, 'heavy precipitation' is defined as the daily precipitation total that is exceeded on just 10% of wet–days. On average, the greatest increase in heavy precipitation occurs in summer (+18%), followed by spring (+12%) and autumn (+10%), with winter returning <1% change. The largest seasonal changes in heavy precipitation intensity occur at Cranwell (+48%) and Raunds (+32%), both in summer. These results are not consistent with recent observed trends in which summer rainfall totals are increasingly dominated by light–intermediate intensity storms (Osborn et al., 2000), but are consistent with GCM results for Europe more generally (Hennessy et al., 1997).

Table 17 further reports seasonal changes in wet–day frequencies between 2080–2099 and 1960–89 under the SDS–2 and SDS–3 scenarios. Under SDS–2, there are modest increases in winter (+7%) and spring (+6%) wet–day occurrence, but declines in summer (–6%) and autumn (–11%). Under SDS–3, there are reductions in wet–day occurrence across all seasons, ranging on average from –23% in summer and autumn, to –5% in spring. The changes in summer rainfall are broadly consistent with observed trends in wet–day probabilities in eastern England (Osborn et al., 2000), which point toward greater persistence of summer dry–spells in 2080–2099. Under both SDS–2 and SDS–3, the greatest reduction in summer wet–days occurs in the south of the Region (Raunds) and the least in the north (Buxton).

**Spatial Variability**

The underlying controls of the spatial variability of climate change reported in Table 15 and 16 were investigated by correlating the station temperature and precipitation changes with station elevation, latitude and longitude (as before with the HadRM2 scenario). Mean annual and summer temperature changes are negatively correlated with latitude, indicating a north–south gradient in the pattern of warming (i.e., greater warming in the south than in the north of the Region). The only other significant (positive) correlation is between the mean annual precipitation change of SDS–1 and latitude, indicating greater reductions in precipitation in the south than the north. Once again, no systematic relationships were found between elevation and either temperature or precipitation.

In summary, the statistically downscaled scenarios suggest greater summer warming than winter warming at all five sites. The SDS–1 scenario indicates reductions in both winter and summer precipitation leading to greater overall reductions at Raunds than at Buxton. Conversely, the SDS–2 scenario indicates increases in both winter and summer precipitation leading to greater overall increases at Cranwell and Raunds than at Buxton. The SDS–2 scenario also returns greater precipitation intensities for the heaviest storms and longer dry–spells between wet–days in the summer. The SDS–3 scenario suggests reductions in both winter and summer precipitation but these changes are more conservative than under SDS–1. Furthermore, the greatest overall precipitation reduction occurs at Skegness (the site of the smallest annual change under SDS–1). The following section accounts for the differences between the SDS, RCM and GCM scenarios.

**Comparison of Regional Climate Change Scenarios**

Four sets of climate change scenario were presented for the East Midlands in 2080–2100. These scenarios include: (1) the UKCIP98 scenarios for Eastern England; (2) analogue scenarios from observed climate data; (3) a climate change scenario produced by the regional climate model HadRM2; and (4) three statistically downscaled climate change scenarios (SDS–1, SDS–2 and SDS–3) for individual sites.

**Tables 18 and 19** summarises the changes in mean annual, winter and summer temperature and precipitation associated with each method of scenario generation. However, it should be emphasised that the HadRM2, HadCM2 (UKCIP98) and SDS scenarios are not strictly comparable. This is because the former two were produced by a greenhouse–gas–only experiment (GGa), whereas the SDS scenarios originate from a greenhouse–gas plus sulphate–aerosol experiment (GSa). For this reason, the two sets of experiments are dealt with separately in Tables 18 and 19.

### HadRM2 (RCM) compared with HadCM2 (GCM)

The following conclusions may be drawn from comparisons amongst the analogue, HadRM2 and HadCM2 scenarios (Table 18).

**Table 18** **Changes in mean annual, winter and summer temperature (ºC) and precipitation (%) for the 2080s in the East Midlands with respect to 1961–1990 means. The results for HadRM2 and HadCM2 were produced from the UKCIP** Medium-high **scenario (a greenhouse–gas–only experiment, GGa). Note that the statistics for HadCM2 reflect the ensemble mean (GGa), whereas the HadRM2 experiment was driven by a single ensemble member (GGa2).**

| Scenario | | Temperature change (ºC) | | | Precipitation change (%) | | |
|---|---|---|---|---|---|---|---|
| | Grid pts. | Annual | Winter | Summer | Annual | Winter | Summer |
| Analogue | 1 | +1.2<br>(1999) | +2.4<br>(1988/89) | +2.0<br>(1995) | +18<br>(1999) | +54<br>(1995/96) | -68<br>(1995) |
| HadRM2 | 12 | +3.0 | +3.5 | +2.6 | +7 | +27 | –26 |
| HadCM2 | 1 | +2.8 | +3.0 | +2.7 | +5 | +19 | –16 |

- All scenarios show annual, winter and summer temperature increases.
- The RCM shows greater annual and winter warming than the GCM.
- Even the most conservative temperature changes predicted by the RCM and GCM are greater than observed rates of warming in the 20th Century.
- The analogues for annual (1999), winter (1988/89) and summer (1995) temperature anomalies were smaller than the temperature changes produced by the RCM and GCM.
- The RCM shows greater seasonal precipitation changes than the GCM.
- The climate analogues for annual (1999), winter (1995/967), and summer (1995) precipitation anomalies were larger than the precipitation changes produced by both the RCM and the GCM.

As noted earlier, the annual temperature and precipitation changes projected by the RCM for the East Midlands are broadly consistent with the climate changes projected by the GCM more generally for Eastern England. However, it should be recognised that the RCM results are for a single model run (GGa2), whereas the GCM results are for the ensemble average (GGa). This means that the internal model variability is damped in the mean results of the GCM.

### 4.3.5 Statistical downscaling (SDS) compared with raw HadCM2 (GCM)

The following conclusions may be drawn from comparisons amongst the analogue, SDS and HadCM2 scenarios (Table 19). In this case, the SDS scenarios and raw GCM output are derivatives of a single ensemble member (GSa1).

**Table 19 Changes in mean annual, winter and summer temperature (ºC) and precipitation (%) for the 2080s in the East Midlands with respect to 1961–1990 means. The statistically downscaled scenarios (SDS–1, SDS–2 and SDS–3) were produced from atmospheric circulation and humidity data provided by the HadCM2 greenhouse-gas-plus-sulphate-aerosols experiment (GSa1) for model years 2080–2099. The statistics of the raw HadCM2 output are given for the same ensemble member.**

| Scenario | | Temperature change (ºC) | | | Precipitation change (%) | | |
|---|---|---|---|---|---|---|---|
| | Grid pts. | Annual | Winter | Summer | Annual | Winter | Summer |
| Analogue | 1 | +1.2 (1999) | +2.4 (1988/89) | +2.0 (1995) | +18 (1999) | +54 (1995/96) | -68 (1995) |
| SDS–1 | 5 | +1.8 | +1.0 | +1.9 | –20 | –20 | –30 |
| SDS–2 | 5 | +1.8 | +1.0 | +1.9 | +11 | +11 | +13 |
| SDS–3 | 5 | +1.8 | +1.0 | +1.9 | –5 | –5 | –11 |
| HadCM2 | 1 | +2.9 | +2.7 | +3.2 | +10 | +16 | +4 |

- The SDS shows less annual, winter and summer warming than the GCM.
- Analogue winter and summer temperature anomalies were greater than the temperature changes produced by SDS.
- The SDS–1 scenario shows reductions in precipitation for all seasons, rather than the increase in seasonal precipitation suggested by the GCM.
- The SDS–2 scenario shows slightly smaller increases in winter precipitation, and slightly larger increases in summer precipitation than the GCM.
- The SDS–3 scenario is qualitatively similar to SDS–1 but the precipitation reductions are smaller in SDS–3.
- Analogues for annual, winter, and summer precipitation anomalies were larger than the precipitation changes of the SDS and the GCM scenarios.

Differences amongst the SDS results highlight the sensitivity of statistically downscaled climate scenarios to the choice of predictor variables (see Charles et al. 1999; Huth, 1999; Wilby and Wigley, 2000). The SDS–1 scenario reflects the climatic consequences of changes in atmospheric circulation patterns **only**. SDS–2 and SDS–3 reflect circulation **plus** humidity changes (albeit specific humidity in the former, and relative humidity in the latter). The two sets of scenarios are, therefore, modelling different components of the climate change signal.

The large rainfall reductions of the SDS–1 scenario are dominated by future increases in the thickness of the lower atmosphere (or 500 hPa geopotential height field), whereas the modest rainfall increases in SDS–2 are largely a consequence of future increases in specific humidity. In comparison, SDS–3 yields a scenario that is intermediate to SDS–1 and SD–2 by using relative humidity as a predictor of precipitation occurrence instead of specific humidity (as advocated by Charles et al., 1999). SDS–3 also implies that future changes in atmospheric circulation (in particular the geopotential heights) have a greater bearing on future rainfall occurrence than changes in atmospheric relative humidity. Overall, however, the SDS–2 scenario is most consistent with the driving GCM scenario. Even so, SDS–2 suggests larger increases in summer precipitation than the GCM.

## 4.4 Concluding remarks

It is tempting to make direct comparisons amongst the various scenarios. However, it should be stressed once again that very different assumptions underpin the RCM and SDS experiments. Most significantly, the RCM and HadCM2 (UKCIP98) scenarios were produced by a greenhouse–gas–only experiment; whereas the SDS scenarios originate from a greenhouse–gas–plus–sulphate–aerosol scenario. Furthermore, the RCM and GCM 'average' climate changes over cells of 2500 $km^2$ and 70,000 $km^2$ respectively; the SDS scenarios estimate climate changes at point locations. The RCM and GCM scenarios use all vertical levels and all aspects of relevant atmospheric behaviour to simulate the grid–box climate change; the SDS scenarios were generated from a relatively small set of predictor variables.

Therefore, the preceding results were intended to illustrate some of the uncertainties associated with climate scenario generation for regions as small as the East Midlands. The results also highlight the need for **multiple** scenarios with which to elucidate future climate change impacts. It must be emphasised that none of the scenarios are intended to be *forecasts*, but rather plausible *realisations* of future regional climate change.

## 4.5 Recommendations for Future Research

The next set of UKCIP climate change scenarios will be published in the autumn of 2001. These scenarios will draw upon revised IPCC emission scenarios as well as the results of new Regional Climate Model experiments. In the meantime, several recommendations are made with respect to improving existing climate change scenarios for the East Midlands:

- Possible changes in other climate variables (such as wind speed, humidity, evaporation and solar radiation) should be considered alongside temperature and precipitation. These data could be obtained from existing RCM experiments or generated using SDS methods;
- Further work should be undertaken to evaluate possible changes in the distributions of *daily* climate variables. Published work on extreme precipitation events (Osborn et al., 2000), for example, could be augmented by similar studies of wind spectra, flooding or drought duration/severity;

- Dynamically and statistically downscaled climate scenarios should be compared to determine the most appropriate combination of predictor variables to represent both the *present*–day climate and future climate *change* across the East Midlands (as in Murphy, 1999; 2000). This would increase the physical realism of the SDS method (within the constraints imposed by the range of archived GCM variables) and ensure greater consistency between the two approaches; and
- Dynamically and statistically downscaled climate scenarios could be used to drive a range of hydrological and agricultural impact models. This would facilitate assessments of the significance of regional climate change relative to historic climate variability (as in Hulme et al., 1999), as well as the significance of model uncertainty (as in Wilby et al., 1999).

## 4.6 References


Alexandersson, H., Tuomenvirta, H., Schmith, T. and Iden, K. 2000. Trends in storms in NW Europe derived from an updated pressure data set. *Climate Research*, **14**, 71-73.

Arnell, N.W., Reynard, N., King, R., Prudhomme, C. and Branson, J. 1997. *Effects of Climate Change on River Flows and Groundwater Recharge: Guidelines for Resource Assessment*. UKWIR/EA Report No. 97/CL/04/1, London, pp55.

Arnell, N.W., Jenkins, A. and George, D.G. 1994. *The Implications of Climate Change for the National Rivers Authority*. National Rivers Authority R and D Report **12**, HMSO, London.

Benner, T.C. 1999. Central England temperatures: long-term variability and teleconnections. *International Journal of Climatology*, **19**, 391-403.

Beven, K. 1993. Riverine flooding in a warmer Britain. *Geographical Journal*, **159**, 157-161.

Boardman, J. and Favis-Mortlock, D.T. 1993. Climate change and soil erosion in Britain. *Geographical Journal*, **159**, 179-183.

Brugge, R. 1993. Drought and disaster in spring 1893. *Weather*, **48**, 134-141.

Buishand, T.A. and Beckmann, B. –R. 2000. Development of daily precipitation scenarios as KNMI. *Climate scenarios for water-related and coastal impact ECLAT–2*. Report No.2, Lage Vuursche Workshop, 10–12 May, 2000, Climatic Research Unit, Norwich, UK, in press

Burt, T.P. and Shahgedanova, M. 1998. An historical record of evaporation losses since 1815 calculated using long-term observations from the Radcliffe Meteorological Station, Oxford, England. *Journal of Hydrology*, **205**, 101-111.

Carter, A.H.C. and Robertson, I. 1998. Relative humidity — A dataset for east England, 1920–95. *Weather*, **53**, 181–189.

Charles, S.P., Bates, B.C., Whetton, P.H. and Hughes, J.P. 1999. Validation of downscaling models for changed climate conditions: case study of southwestern Australia. *Climate Research*, **12**, 1–14.

Cole, J.A., Slade, S., Jones, P.D. and Gregory, J.M. 1991. Reliable yield of reservoirs and possible effects of climate change. *Hydrological Sciences Journal*, **36**, 579-598.

Conway, D. 1998. Recent climatic variability and future climate change scenarios for Great Britain. *Progress in Physical Geography*, **22**, 350-374.

Conway, D. and Jones, P.D. 1998. The use of weather types and airflow indices for GCM downscaling. *Journal of Hydrology*, **212**, 348-361.

Conway, D., Wilby, R.L. and Jones, P.D. 1996. Precipitation and air flow indices over the British Isles. Special Issue of *Climate Research*, **7**, 169-183.

Doornkamp, J.C. 1993. Clay shrinkage induced subsidence. *Geographical Journal*, **159**, 196-202.

Ferrier, R.C., Whitehead, P.G. and Miller, J.D. 1993. Potential impacts of afforestation and climate change on the stream water chemistry of the Monachyle catchment. *Journal of Hydrology*, **145**, 453-466.

Foster, I.D.L. 1995. Lake and reservoir bottom sediments as a source of soil erosion and sediment transport data in the UK. In: Foster, I.D.L., Gurnell, A.M. and Webb, B.W. (Eds), *Sediment and Water Quality in River Catchments*, Wiley, Chichester.

Giorgi, F. and Mearns, L.O. 1991. Approaches to the simulation of regional climate change. A review. *Rev. Geophys.*, **29**, 191-216.

Giorgi, F. and Mearns, L.O. 1999. Introduction to special section: Regional climate modeling revisited. *Journal Geophysical Research*, **104**, 6335-6352.

Gregory, J.M., Jones, P.D. and Wigley, T.M.L. 1991. Precipitation in Britain: an analysis of area average data updated to 1989. *International Journal of Climatology*, **11**, 331-345.

Heathwaite, A.L. 1993. Disappearing peat – regenerating peat? The impact of climate change on British peatlands. *Geographical Journal*, **159**, 203-208.

Hennessy, K.J., Gregory, J.M. and Mitchell, J.F.B. 1997. Changes in daily precipitation under enhanced greenhouse conditions. *Climate Dynamics*, **13**, 667-680.

Hulme,M., Barrow, E.M., Arnell, N., Harrison, P.A., Downing, T.E. and Johns, T.C. 1999. Relative impacts of human-induced climate change and natural climate variability. *Nature*, **397**, 688-691.

Hulme, M. and Jenkins, G. 1998. *Climate change scenarios for the United Kingdom.* UKCIP Technical Note 1, Climatic Research Unit, Norwich, UK, 80pp.

Hulme,M., Hossell, J.E. and Parry, M.L. 1993. Future climate change and land use in the United Kingdom. *Geographical Journal*, **159**,131-147.

Huth, R. 1999. Statistical downscaling in central Europe: evaluation of methods and potential predictors. *Climate Research*, **13**, 91–101.

Jones, D.K.C. 1993. Global warming and geomorphology. *Geographical Journal*, **159**, 124-130.

Jones, D.K.C. 1993. Slope stability in a warmer Britain. *Geographical Journal*, **159**, 184-195.

Jones, P.D. and Conway, D. 1997. Precipitation in the British Isles: an analysis of area-average data updated to 1995. *International Journal of Climatology*, **17**, 427-438.

Jones, P.D. and Hulme, M. 1997. The changing temperature of Central England. In. Hulme, M. and Barrow, E.M. (eds.) *Climates of the British Isles: Present, past and future.* Routledge, London, UK, 127pp.

Jones, P.D. and Lister, D.H. 1998. Riverflow reconstructions for 15 catchments over England and Wales and an assessment of hydrologic drought since 1865. *International Journal of Climatology*, **18**, 999-1013.

Jones, P.D., Horton, E.B., Folland, C.K., Hulme, M., Parker, D.E. and Basnett, T.A. 1999. The use of indices to identify changes in climatic extremes. *Climatic Change*, **42**, 131-149.

Jones, R.G., Murphy, J.M. and Noguer, M. 1995. Simulation of climate change over Europe using a nested regional-climate model. I: Assessment of control climate, including sensitivity to location of lateral boundaries. *Journal of the Royal Meteorological Society*, **121**, 1413-1449.

José, P. 1989. Long-term nitrate trends in the River Trent and four major tributaries, *Regulated Rivers*, **4**, 43-57.

Klein, W.H. and Glahn, H.R. 1974. Forecasting local weather by means of model output statistics. *Bulletin of the American Meteorological Society*, **55**, 1217-1227.

Lockwood, J.G. 2000. Some comments on long–term trends observed in an east England relative humidity dataset. *Weather,* **55**, 170–174.

Manley, G. 1953. Mean temperature of central England. *Quarterly Journal of the Royal Meteorological Society*, **79**, 242-261.

Manley, G. 1974. Central England temperatures: monthly means 1659 to 1973. *Quarterly Journal of the Royal Meteorological Society*, **100**, 389-405.

Marsh, T.J. and Monkhouse, P.S. 1996. Drought in the United Kingdom, 1988-92. *Weather*, **46**, 365-376.

Marsh, T.J. and Turton, P.S. 1996. The 1995 drought - a water resources perspective. *Weather,* **51**, 46-53.

Mayes, J.C. 1991. Recent trends in summer rainfall in the UK. *Weather*, **46**, 190-196.

Mayes, J. 1996. Spatial and temporal fluctuations of monthly rainfall in the British Isles and variations in the mid-latitude westerly circulation. *International Journal of Climatology*, **16**, 585-96.

Mayes, J.C. 1998. United Kingdom summer weather over 50 years - continuity or change? *Weather,* **53**, 2-11.

Murphy, J. 1999. An evaluation of statistical and dynamical techniques for downscaling local climate. *Journal of Climate*, **12**, 2256-2284.

Murphy, J. 2000. Predictions of climate change over Europe using statistical and dynamical downscaling methods. *International Journal of Climatology*, **20**, 489–501.

New, M. 1999. Uncertainty in representing the observed climate. In, Carter, T.R., Hulme, M. and Viner, D. (eds.) *Representing uncertainty in climate change scenarios and impact studies*. Proceedings of the ECLAT-2 Helsinki Workshop, 14-16 April 1999, Climatic Research Unit, Norwich, UK, pp.59-66.

Newson, M. and Lewin, J. 1991. Climatic change, river flow extremes and fluvial erosion - scenarios for England and Wales. *Progress in Physical Geography*, **15**, 1-17.

O'Hare, G.P. and Wilby, R.L. 1995. Ozone pollution in the United Kingdom: an analysis using Lamb circulation types. *Geographical Journal*, **161**, 1–20.

Osborn, T.J., Hulme, M., Jones, P.D. and Basnett, T.A. 2000. Observed trends in the daily intensity of United Kingdom precipitation. *International Journal of Climatology*, **20**, 347-364..

Parker, D.E., Legg, T.P. and Folland, C.K. 1992. A new daily central England temperature series 1772-1991. *International Journal of Climatology*, **12**, 317-342.

Parry, M.L., Hossell, J.E., Jones, P.J., Rehman, T., Tranter, R.B., Marsh, J.S., Rosenzweig, C., Fischer, G., Carson, I.G. and Bunce, R.G.H. 1996. Integrating global and regional analyses of the effects of climate change: a case study of land use in England and Wales. *Climatic Change*, **32**, 185-198.

Pethick, J. 1993. Shoreline adjustments and coastal management: physical and biological processes under accelerated sea-level rise. *Geographical Journal*, **159**, 162-168.

Pilling, C. and Jones, J.A.A. 1999. High resolution climate change scenarios: implications for British runoff. *Hydrological Processes*, **13**, 2877-2895.

Robson, A.J., Jones, T.K., Reed, D.W. and Bayliss, A.C. 1998. A study of national trend and variation in UK floods. *International Journal of Climatology*, **18**, 165-182.

Rumsby, B.T. and Macklin, M.G. 1994. Channel and floodplain response to recent abrupt climate change: the Tyne Basin, Northern England. *Earth Surface Processes and Landforms*, **19**, 499-515.

Shennan, I. 1989. Holocene crustal movements and sea level changes in Great Britain. *Journal of Quaternary Science*, **4**, 77-89.

Shennan, I. 1993. Sea-level changes and the threat of coastal inundation. *Geographical Journal*, **159**,148-156.

Smith, K. 1995. Precipitation over Scotland, 1757-1992: some aspects of variability. *Journal of Climatology*, **15**, 543-556.

Subak, S., Palutikof, J.P., Agnew, M.D., Watson, S.J., Bentham, C.G., Cannell, M.G.R., Hulme, M., McNally, S., Thornes, J.E., Waughray, D. and Woods, J.C. 2000. The impact of the anomalous weather of 1995 on the U.K. economy. *Climatic Change*, **44**, 1-26.

Webb, B.W. 1996. Trends in stream and river temperature behaviour. *Hydrological Processes*, **10**, 205–226.

Wheeler, D. and Mayes, J. (eds.) 1997. *Regional climates of the British Isles*. Routledge, London.

Whitehead, P.G., Black, V., Jenkins, A., Wright, R. and Cosby, J. 1993. Modelling acidification at Beacon Hill – a low rainfall, high pollutant deposition site in central England. *Environmental Pollution*, **79**, 277–281.

Wilby, R.L. 1994. Exceptional weather in the Midlands, UK during 1988-1990 results in the rapid acidification of an upland stream. *Environmental Pollution*, **86**, 15–19.

Wilby, R.L. 1995. Greenhouse hydrology. *Progress in Physical Geography*, **19**, 351-369.

Wilby, R.L. 1996. Critical loads' sensitivity to climate change. *Environmental Conservation*, **22**, 363–365.

Wilby, R.L. 1998. Hydrological impacts of the National Forest. *East Midlands Geographer*, **21**, 71–77.

Wilby, R.L. and Wigley, T.M.L. 1997. Downscaling General Circulation Model output: a review of methods and limitations. *Progress in Physical Geography*, **21**, 530–548.

Wilby, R.L. and Wigley, T.M.L. 2000. Precipitation predictors for downscaling: observed and General Circulation Model relationships. *International Journal of Climatology*, **20**, 641–661.

Wilby, R.L., Conway, D. and Jones, P.D. 2000. Prospects for downscaling seasonal precipitation variability using conditioned weather generator parameters. *Hydrological Processes*, in press.

Wilby, R.L., Dalgleish, H.Y. and Foster, I.D.L. 1997a. The impact of weather patterns on contemporary and historic catchment sediment yields. *Earth Surface Processes and Landforms*, **22**, 353–363.

Wilby, R.L., Hay, L.E. and Leavesley, G.H. 1999. A comparison of downscaled and raw GCM output: implications for climate change scenarios in the San Juan River basin, Colorado. *Journal of Hydrology*, **225**, 67-91.

Wilby, R.L., Hay, L.E., Gutowski, W.J., Arritt, R.W., Takle, E.S., Pan, Z., Leavesley, G.H. and Clark, M.P. 2000. Hydrological responses to dynamically and statistically downscaled climate model output. *Geophysical Research Letters*, **27**, 1199–1202.

Wilby, R.L., O'Hare, G. and Barnsley, N. 1997b. The North Atlantic Oscillation and British Isles climate variability 1865-1995. *Weather*, **52**, 266–76.

Wild, R., O'Hare, G. and Wilby, R.L. 1996. A historical record of blizzards/ major snow events in the UK and Ireland, 1880-1989. *Weather*, **51**, 82–91.

Wilkinson, W.B. and Law, F.M. 1990. Engineering design for climatic extremes. *Weather*, **45**, 138-145.

Winkler, J.A., Palutikof, J.P., Andresen, J.A. and Goodess, C.M. 1997. The simulation of daily temperature series from GCM output. Part II: Sensitivity analysis of an empirical transfer function methodology. *Journal of Climate*, **10**, 2514-2532.

Woodworth, P.L. 1991. The Permanent Service for Mean Sea Level and the Global Sea Level Observing System. *Journal of Coastal Research*, **7**, 699-710.

Woodworth, P.L., Tsimplis, M.N., Flather, R.A. and Shennan, I. 1999. A review of the trends observed in British Isles mean sea-level data measured by tide gauges. *Geophysical Journal International*, **136**, 651-670.

**Table 20 A survey of literature concerned with climate variability, climate change and potential environmental impacts in the UK.**

| *Variables considered* | *Author(s)* |
|---|---|
| **Climatic**<br>Central England Temperature in relation to the North Atlantic Oscillation | Benner (1999) |
| Trends in relative humidity at sites in eastern England | Carter and Robertson (1998) |
| Review of temperature, precipitation and hydrological variability | Conway (1998) |
| Regional precipitation changes in relation to airflow indices | Conway et al. (1996) |
| Long-term trends in area-average precipitation | Jones and Conway (1997) |
| Central England Temperature variability | Jones and Hulme (1997) |
| Trends in summer rainfall | Mayes (1991) |
| Rainfall variability in relation to the mid-latitude westerly circulation | Mayes (1996) |
| Trends in summer weather indices | Mayes (1998) |
| Trends in the daily probability and intensity of rainfall | Osborn et al. (2000) |
| Update and analysis of the Central England Temperature series | Parker et al. (1992) |
| Trends in Scottish rainfall | Smith (1995) |
| Review of temperature, precipitation and hydrological variability | Wilby (1995) |
| Atmospheric circulation patterns in relation to catchment sediment yields | Wilby et al. (1997a) |
| Regional climate variability in relation to the North Atlantic Oscillation | Wilby et al. (1997b) |
| Trends in the frequency and severity of blizzards/major snowfalls | Wild et al. (1996) |
| **Sea-level/coastal**<br>Trends in synoptic-scale storminess | Alexandersson et al. (2000) |
| Physical and biological consequences of sea-level rise | Pethick (1993) |
| Sea-level change and the threat of coastal inundation | Shennan (1993) |
| Sea-level changes | Woodworth et al. (1999) |
| **Hydrological**<br>River flows and water resources | Arnell et al. (1994, 1997) |
| River flooding | Beven (1993) |
| Reliable yield of reservoirs | Cole et al. (1991) |
| Changes in stream water chemistry | Ferrier et al. (1993) |
| Upland and lowland peatland environments | Heathwaite (1993) |
| Changes in regional runoff | Pilling and Jones (1999) |
| Trends and regional variations in floods | Robson et al. (1998) |
| Trends in river water temperature | Webb (1996) |
| Surface water acidification and critical loads | Wilby (1996) |

| *Variables considered* | *Author(s)* |
|---|---|
| Water resource engineering for climatic extremes | Wilkinson and Law (1990) |
| **Geomorphological**<br>Soil erosion | Boardman and Favis-Mortlock (1993) |
| Drought induced subsidence | Doornkamp (1993) |
| Spatial extent, scale and significance of slope stability | Jones (1993a,b) |
| Extreme river flows and fluvial erosion | Newson and Lewin (1991) |
| Channel and floodplain changes | Rumsby and Macklin (1994) |
| **Miscellaneous**<br>Land use change in the United Kingdom | Hulme et al. (1993) |
| Surface ozone concentrations in relation to atmospheric circulation | O'Hare and Wilby (1995) |
| Land use change in England and Wales | Parry et al. (1996) |

# 5. Potential Impacts of Climate Change and Adaptation Options in the East Midlands

*Main Author: Dr Simon Shackley, UMIST*

## 5.1 Introduction

Where possible, climate change impact assessment provides a quantitative indication of change in system variables. This usually necessitates use of a computer-based simulation model. Yet such models are only now becoming available at the sub-UK scale, eg through the REGIS project, and their application is a major (and expensive) research effort. Furthermore, for many socio-economic and environmental systems, quantitative characterisation is difficult or yet not achieved. Alternative approaches to are to: a) extrapolate findings from existing literature where modelling has been accomplished; b) draw upon expert opinion; and/or c) draw upon stakeholder opinion. In this section, we attempt to do (a) by reviewing the formal literature as referenced in past regional and sectoral climate change studies, and in electronic databases such as BIDS. Steps b) and c) are included in Chapter 6. We have included some 'grey' literature where available to us but are aware that there are other sources of information we have not yet identified or made use of. We have aimed to draw upon expert and stakeholder opinion through 5 workshops, and 3 additional meetings, which were held in April to June 2000 across the Region (discussed in section 6.2). In addition, a number of telephone interviews (approximately 10) have been conducted to obtain further sources of information, eg with the commercial and business sector.

Climate change impact assessment to the 2020s or the 2050s has to take account of other environmental and socio-economic changes. As Hulme et al. (1999) point out, this includes natural climate variability; they find that in certain cases over the next few decades natural variability in climate may have a greater impact upon the weather than the predicted climate change. This implies that adaptation to multi-decadal natural climate variability may be a sufficient medium-term response in certain regions and sectors - although, as Hulme et al. state, in other sectors and regions it would not. Socio-economic changes are in many cases more important drivers than climate change. Crosson and Rosenberg (1993) caution against taking assumptions of current economic activity continuing through until 2030 since there will be an adaptation of management practices in response to multiple drivers and pressures, in agriculture for example. Indeed, many socio-economic systems are highly dynamic and their future vulnerability to climate change cannot by definition be known with any reliability, though it is possible to identify some impact domains that are more vulnerable to others because of topography, geography and other physical constraints. Use of a set of future socio-economic scenarios is emerging as the most appropriate methodology by which to account for socio-economic change (eg those produced by Berkhout et al. for DETR (1999)).

## 5.2 Classification of Impact Domains

We have distinguished between sectors or discrete environmental systems which constitute climate change impact domains. In the discussion of each impact domain, we have first provided the findings from other studies that are of general relevance to the East Midlands. This approach allows us to draw upon the state-of-the-art findings of other regional, sub-UK and sectoral studies such as those for: North West England (Shackley et al., 1998), Scotland (Kerr et al., 1999), South East England (Wade et al., 1999) and others presented in the UKCIP Technical Report (McKenzie-Hedger, 2000). (The full set of references is provided in the bibliography at the end of the chapter). We have then presented the findings that are more specific and particular to the East Midlands, or where good examples of the impact area occur in the East Midlands Region. These classifications are set out below:

## 5.3 Sectors/Systems

5.3.1. Agriculture and Horticulture

5.3.2. Forestry

5.3.3. Water Resources

- Quantity
- Quality
- Flooding

5.3.4. Biodiversity

5.3.5. Cultural Heritage

5.3.6. Leisure and Tourism

5.3.7. Transport

5.3.8. Built Environment

- Domestic
- Commercial

5.3.9. Manufacturing, Services and Retail

5.3.10. Financial Services (including insurance)

5.3.11. Public Health

5.3.12. Energy

5.3.13. Coastal Zone

### 5.3.1 Agriculture and Horticulture

Agriculture and horticulture will be affected by climate change, though it is not possible at present to give a detailed analysis of what changes will occur. The REGIS project funded by

MAFF, DETR and UKWIR is developing an integrated assessment of climate change impacts which uses a land-use model at its core. This approach could be extended to the East Midlands to provide more quantitative analysis of what changes might be expected under different scenarios. Agriculture is made up of a large number of individual economic units and decision-makers. The perception of, and response to, climate change is likely to vary significantly between individual units, as illustrated by the Vining Peas study reported below.

**General Findings on Agriculture and Climate Change of Relevance to the East Midlands**

- Increased temperature across all seasons leading to longer growing seasons.
- Potential to grow different crop types such as grain maize, sunflowers, soya.
- Increased risk of summer drought, especially on thin, sandy and chalky soils.
- Shift to autumn planting if soil is workable.
- Increase in soil erosion.
- Increased demand for water irrigation, especially horticultural sector.
- Change in the timing and incidence of pests of crops and livestock.
- Risk of over-heating of livestock.

Sunflowers: A replacement for winter oilseed rape? Oilseed rape yields would decline if moisture in the autumn is not sufficient to allow crop establishment and if there are summer droughts.

Grain Maize and Soyabeans: Grain maize would require investment in irrigation equipment. Irrigation would be necessary to ensure the quality and predictability of yields, as opposed to the cultivation of forage maize.

Salad Crops: Benefits from reduced heating of glasshouses. Reduced cloud cover in 1995 led to increased yields of tomatoes and cucumbers.

Plant Breeding: New varieties may be required for some crops, eg slower maturing varieties of wheat, lettuce and carrot.

Grassland: Increased growing period, but possibility of water deficit leading to earlier dieback and lack of fodder for livestock in the winter. This may encourage farmers to put more land into silage production, which could have a knock-on effect upon biodiversity by reducing the amount of flower-rich grassland.

Livestock: Pig and poultry production declined in very hot conditions of 1995 (reduction in weight and for poultry the number of eggs). Milk yields were also down in 1995 and the lambing rate was down in the following Spring. This could require, for intensive livestock rearing, ventilation devices, sprinklers, etc. or a move to extensive production, with implications for soils and water requirement (outdoor rearing pigs requiring 50-70% more water). In upland areas, stock can be put onto the land earlier – and perhaps all year around – reducing livestock housing and transport costs, but increasing the risk of soil erosion.

Soil Erosion: Farmers have expressed concerns about intense rainfall events causing soil erosion. New crops such as maize could increase vulnerability to intensive rainfall.

Autumn Soil Tillage: An increase in temperature would allow some improvements in soil tillage, whilst an increase in precipitation would be more of a problem. Overall, a decrease in precipitation would have a greater positive effect on machine work days. For England and Wales as a whole, the benefits of a 2°C rise would be totally offset if precipitation were to increase by 10%.

Planting Times: Planting in autumn may be preferred to allow establishment before dry conditions set in during the summer, depending on autumn soil wetness. (In France, farmers sow winter oilseed in the autumn if conditions are suitable; if not, they sow sunflowers in the spring instead).

Pests and Diseases: Warmer drier conditions may encourage some pests (eg red spider mite, aphids and cutworms) but deter others. The summer of 1995 reduced carrot fly damage in parsnips and carrots as this pest was limited by hot dry soils. Warm wet winters and drier summers (eg in 1990) favour spread of soil-borne cereal diseases such as ‘take-all’.

Extreme Events: short-term high temperatures can lead to reproduction development and loss of starch in cereal grains, and warming in spring can increase vulnerability to late frosts.

Pesticides and Herbicides: Pollution risks increase due to intense rainfall events and due to cracking of soils.

Availability of Water for Agriculture: The 1995 drought reduced yields of salad and horticultural crops (especially peas, carrots, onions, potatoes, salad onions and leeks) and fruit (on shallow soils) but cereals benefited. Protected salad crops did benefit, albeit at higher costs for carbon dioxide fertilisation due to the required additional ventilation. Overall costs to agriculture nationally from the 1995 drought have been estimated at £280 million. One study of the impacts of climate change found that the amount of available land well suited for winter wheat declines with a rise in temperature and constant, or a 10% increase in, precipitation. Much of the moderately suited land becomes more marginal. Maize may replace some wheat but needs irrigating to avoid drought. Coarser soils are an important limiting factor during periods of drought for short term vegetables, such as lettuce, with roots less than 0.3m. Whilst irrigation may be profitable for high value crops it is not for cereals or sugar beet. There is currently no consensus about whether plants will use water more efficiently under higher $CO_2$ conditions.

Working Conditions: The summer of 1995 reduced the harvesting period which meant long working days for the agricultural workers, and the increased need for irrigation also placed additional demands on labour.

**Findings Specifically Related to the East Midlands**

Sea level rise and coastal flooding is one of the key impacts of climate change for agriculture. The percentage of the Agricultural Land Classification (ALC) grades, representing the proportion of that land within the East Midlands below the 5m contour are as follows:

Grade 1: 99%

Grade 2: 35%

Grade 3: 6%

Grade 4: 2%

Grade 5: 0%

75% of the land below the 5m contour line is either Grade 1 or Grade 2. An area of 1460 $km^2$ is protected from tidal flooding and, but for the presence of flood defences, would be regularly inundated (MAFF 2000). The high economic value of such land clearly demonstrates the potentially major implications of climate change.

Even though new opportunities will be taken to grow a wider range of crops in the East Midlands, it is unlikely that there will be a whole scale change in the short- to medium-term from grass and livestock to arable crops such as cereals in areas where long-term grassland and rough grazing predominate, such as the Peak District (Alasdair Sellers, personal communication, June 2000). Such a change would require significant changes to the present infrastructure and socio-economic structure of farming, which would require relatively high levels of capital investment. There may, for example, be a need to provide new facilities, new equipment, or put in place mechanisms such as central crop stores or machinery rings to share the cost of the necessary infrastructure (ibid.). It is also unlikely that sheep farms would convert to dairy, as this also has high capital establishment costs. Such costs are likely to rise also, as the trend is for milk production to be concentrated into a smaller number of large units. In the Peak, for example, the Agricultural Census shows that there was a 17% reduction in the number of dairy farmers between 1987 and 1997 (ibid.).

***Vining Peas in Lincolnshire***

Holloway and Ilbery (1997) have examined the impacts of climate change upon pea growers in Lincolnshire. Vining peas are grown in Lincolnshire and sold as frozen peas under contract to large food processors. The crop is sensitive to a relatively small rise in average temperatures. Timing of production is very important, with peas being drilled to a strict planting schedule which relies on knowledge of average climate conditions to enable prediction of when the crop will be ready for harvest. In hot weather, a crop of peas may go past its acceptable harvest period in less than a day. Modelling showed that the period available for harvesting could be reduced by 25% with a warming of 0.5°C during the harvest period. The total time available for harvesting the crop could be squeezed if temperatures rise. The location of the freezer plant is critical – peas need to be frozen within 90 minutes of being harvested in order to maintain acceptable quality (i.e. a 30-35 mile radius). A survey revealed that 19 vining pea farmers thought that global warming would cause problems, whilst 11 thought that it would not have serious impacts. The issues raised by climate change included the following:

- Reduction in total harvesting and planting season – less time to get the crop in from an individual field, and concertina effect on whole growing season. “One of the [farmers’] spokesmen said that a dry summer / wet winter scenario would be horrendous, giving a much narrower drilling window and further restricting scheduling [of planting]” (ibid.:232). Seeds planted in soft damp conditions at the end of a wet winter would be more vulnerable to water shortage during the summer, giving a lower yield.

- Summer drought: the severe droughts of 1975 and 1976 had a very adverse effect on the pea industry. In 1995 the high temperatures caused the peas to mature very rapidly and it proved impossible to find sufficient processing capacity to deal with all of the crop. Part of the crop was not harvested, so reducing yields (Wade et al., 1999:39).
- The physiology of the plants is different depending on when they are planted due to differences in soil and air temperature.
- Pests and weeds. One researcher thought that pea weevil and pea aphid would begin to move earlier because of higher spring temperatures. This could require greater application of pesticide. Weeds (such as couch grass, dock and cow parsley) might lengthen their growing season.

### *Evaluation of Possible Responses*

- Adjustments in the planting schedule to ensure greater allocation of degree days between drillings.
- New plant varieties with different maturation rates could be developed. New drought-tolerant varieties are possible, but considered difficult to obtain.
- Extension of harvesting season limited by suitable weather in autumn. If weather was cool during harvesting time, the freezing plant would be under-utilised and is expensive to turn off and on.
- Another solution is to increase harvesting capacity, eg increased investment in mobile viners (with costs borne by farmers or cooperatives) and freezing plant. Not evident, however, that excess capital would be available for such investment.
- Irrigation would be expensive, but may be necessary.
- Northwards movement of vining pea production is limited by the fixed installation of freezing factories (representing large capital investment).
- The attitude of the food processing companies is summarised as follows: "one of these [representative of company] was very sceptical towards the idea of global warming and had no contingency plans to allow for it; another had already considered the idea seriously, had conducted his own research, and had modified planting schedules for a rise in average temperature which he had himself observed ..…. It is difficult to make adjustments when uncertainty still surrounds the extent and nature of climatic change" (ibid:235).

### *Grazing Pressures, Intensive Rainfall and the Peak District*

Erosion in the uplands has become a more serious problem in the last 20 years, causing down-stream flooding and greater siltation. A debate has arisen about the cause of this erosion. On the one hand, there is the observed pattern of increased winter rainfall. On the other hand, there is the influence of increased grazing pressure. It was found on the north Derwent catchment in the Peak District, that as sheep numbers rose from 12,000 in 1944 to 24,000 in 1975, the runoff rate increased by about 25% (Johns 1998 after Evans 1990). With the recent trend for all-year round grazing on the uplands, vegetation has had very little chance to recover (Johns 1998). It is believed by these experts and some others (eg Orr, pers.com.) that overgrazing and other forms of land management have much greater impact on the sensitivity of land to erosion than climate change.

***Sugar Beet Yields***

Jaggard, Dewar and Pidgeon (1998) found that for sugar beet the mean loss due to drought stress between 1980 and 1995 was 10.5% of production. It was noted that sugar beet suffers comparably less from drought on the near continent, due to higher summer rainfall in the beet growing areas of Germany (Gottingen) and the Netherlands. Also, the higher rates of evapotranspiration was compensated by deeper soils than those under study in Eastern England. In addition they note that the increased green leaf area of sugar beet, bred to improve yields has led to greater water demand by the plant.

***Water Abstraction for Agriculture in the East Midlands***

At the national scale, agriculture represents only 1-2% of total water demand, but at the local level it can be much higher - and with demand often highest when supplies are most depleted. 58% of the East Midlands area is closed to further summer abstraction (Environment Agency 1999) – these areas included most of Lincolnshire, North Nottinghamshire, East Leicestershire, Rutland and Northamptonshire. The vulnerability of groundwater supplies is described as ‘very high’ in central and north Nottinghamshire, and East Lincolnshire and mid Lincolnshire (Environment Agency 1999). This has implications for the sustainability of intensive farming on the “droughty” sandy soils of Nottinghamshire. Use of irrigation water is necessary in much horticulture because the supermarket chains expect uniformity in the produce that goes onto shelves. Potatoes, for example, often develop scars if they do not receive water at exactly the right times. Hence, to produce the 'perfect' potato requires irrigation. Likewise, food processors such as crisps manufacturers will specify a potato without scars. The problem of water abstraction due to climate change is difficult to specify in detail because of scientific uncertainty in the future distribution of rainfall. Nevertheless, the question must be posed of whether the sandy soils of Nottinghamshire should still be used to cultivate potatoes in a changed climate? Perhaps a better option is reversion to the heathlands which once occurred there? Certainly, more winter storage of water will be required since restrictions on irrigation are likely to exceed the licenced volume of irrigation water. There may be a need for grant aid support to help farmers develop winter water storage reservoirs.

***Impacts on Horticulture***

Many of the horticultural producers in the East Midlands grow under glass and hence are not so vulnerable to external conditions. In fact, one grower considered that there would be a benefit in terms of reduced heating bills from an increase in winter temperatures (A.Pederson, personal communication, June 2000). Energy is a major part of the variable costs of glass house production. The glasshouse environment is highly controlled through taking external conditions (temperature, windspeed, etc.) into account. There may be a potential problem arising from restrictions on water availability in the future due to climate change. Water demand would go up with higher external temperatures and there may be a need to top-up rainwater which is collected from glasshouses with tap water. A possible response would be to develop more winter water storage facilities. A greater concern to the glass house growers at present is the Climate Change Levy. For one company, payment of the CCL would have reduced last year's profits to nothing. The CCL could affect international competitiveness. The Government intends to introduce a package of measures to help improve energy efficiency in the horticultural sector while protecting its competitiveness.

***The Role of Socio-Economic Change in Assessing Impacts on Agriculture***

One scenario put forward by Parry et al (1996) assumes that if climate were to remain stable then cereals would disappear from Lincolnshire due to increase competition from abroad under a liberalised trade regime. Under a scenario of 2x$CO_2$ concentration climate change plus trade liberalisation, cereal production moves further north and west in the East Midlands.

### 5.3.2 Forestry

**General Findings on Forestry and Climate Change of Relevance to the East Midlands**

- Increased risk of tree stress and loss from drought
- Increased risk of fire damage
- Greater risk of windthrow for stressed trees – especially relevant for the Peak District.
- Higher growth rates from higher temperatures and $CO_2$ fertilisation but quality compromised by drought, pests, etc.
- Potential for increased damage from pests, pathogens and diseases.
- Change in competitive mix of forest species.
- Potential for increased evapotranspiration from trees compared to other land-uses. This might reduce water availability to support wetland habitats or for other human uses.

Drought: Trees are weakened by drought and become more susceptible to diseases. Establishment of saplings may be especially threatened. The composition of species may change, with drought-tolerant varieties doing better. Species of potential use in short rotation coppicing, such as willows and poplars, may be adversely affected by drought.

Pests and Diseases: Following the 1995 drought, an unusual number of trees died and it is expected that they may have been suffering from root diseases.

Change in Species Mix: There is some evidence that species which do not require a period of winter chilling to trigger bud burst are unfurling leaves earlier. This could give such species a competitive advantage.

**Specific Findings on Forestry and Climate Change in the East Midlands**

More and earlier growth of tree species is expected with warmer temperatures, affecting younger more than older trees. Drought may affect trees stands on sandy soils such as Sherwood Forest particularly those with shallow roots systems. Beech and ash seen to be most at risk from droughts in marginal sites. Oaks are also under threat from a combination of warmer winters, lowering water tables and air pollution (East Midlands Regional Biodiversity Forum, 1999). Forestry may become viable at higher altitudes - the limit being raised from 500m to 600m (ibid). However, this is largely hypothetical given: the poor soil conditions of the High Peak, the fact that the moor tops are exposed to high winds, and the wide spread opposition to extension of plantations in the uplands. More important for the uplands - and throughout the East Midlands generally - is the improved management of existing woodlands, which were once coppiced and have deteriorated since the market for coppiced products collapsed. Small areas of woodland such as the Lincolnshire limewoods need to be extended by creating habitat corridors between existing clusters. By siting the corridors on water courses, the woodland can provide a buffer zone for nutrient leaching into waterways, and assist in providing flood protection.

The water take of forests compared to other land use types on aquifers is an important issue given the decreasing water levels in Sherwood and north Lincolnshire aquifers. A project is underway to measure the water uptake requirements of different land types (Project Tadpole, run by the University of Loughborough), though it is too early to report on the findings (Mathew Woodcock, pers.com., July 2000). There may be opportunities for existing woodland to be converted back to wet heathland, but such biodiversity policies should not result in a loss of woodland.

Urban trees can be beneficial in reducing the extreme temperatures induced by the urban heat island effect, and can reduce the drying out of clay soils where subsidence can be a risk, if the roots place no risk to the foundations. However, certain tree species themselves may become susceptible to climate change in urban areas, and future planting may need to account for this in choice of species.

A major issue for forestry is the potential for trees to be included in carbon sequestration strategies. To this end, the Forestry Commission is calculating the carbon uptake of forests and woods in the East Midlands by using calculations based on the yield categories and areas of different types of woodland. Other initiatives include use of biomass as a renewable energy source. The wood-fired gassification plant at Eggborough in south Yorkshire is being supplied with wood from a 40 mile radius, which includes supplies from the East Midlands and wood coppicing grants have been made available to encourage such supplies. A new NFFO plant running on straw, coppiced material and forestry residues is being built soon in Corby. In the longer-time, new fuels may be produced from biomass and research is underway at the region's universities on a possible biomass-based aviation fuel, for example.

The Forestry Commission is exploring the opportunities for implementing a 'wood heat' project for schools and public buildings which has been trialed in the South West of England. Such small-scale boilers based on wood chips would require a very local supply to avoid additional transport costs. There may be particular opportunities for wood chip boilers in the old coalfield areas, where existing boilers can be adapted.

### 5.3.3 Water Resources and Inland Flooding

> *"...A mean warming of a degree or two does not strike fear into planners hearts. It is more frequent droughts, heatwaves, floods, storms, and even cold spells which will do the economic damage ..".* Burroughs (1997:203)

All aspects of water resource management are potentially influenced by climate change, from water quantity and quality issues, to flooding. Much of the problem in responding to climate change at present is the high uncertainty associated with climate change scenarios, especially regarding changes in variability and extreme events, to which the water resource sector is most vulnerable.

**General Findings on Water Resources and Climate Change of Relevance to the East Midlands**

- Increased risk of extremely low rainfall, including possibility of 'back-to-back' drought years.
- Difficulty of meeting summer peak demands when supply side most stressed by lower rainfall.
- Over-abstraction already of many existing aquifers
- Uncertainty over whether increased winter rainfall / reduced summer rainfall will result in a net increase in the recharge of aquifers. Also reduced period available for recharge due to higher temperatures and increased demand from vegetation.
- Low-flows reducing the dilution of effluent discharge from sewage works, industrial facilities, farming, etc.
- High concentration of pollutants in the first-flush when rainfall ends a dry period. Water companies may be reluctant to abstract from rivers due to high pollutant concentrations in the first-flush events, but thereby lose water.
- An increase in erosion in the uplands has led to more siltation, eg the Pennine reservoirs have been silted up to 7.5% of their capacity - or around 25 days supply.
- Studies of a flood in Somerset by Clark (2000), and a flood in Warwickshire by Harrison and Foster (1999), both come to the conclusion that land use change is a significant contributory factor in exacerbating flood events. Both point out that arable crops such as maize or oil seed rape planted on soils liable to erosion (such as silty soils) leave the soils exposed as they provide minimal cover during their early stages of growth. Soil erosion and floods could be an increasing problem with the increasing amount of maize cultivated under a warmer regime together with a change in rainfall patterns.
- Increasing stress on minor aquifers and private surface water supplies.
- Micro-components analysis of changes in demand for water due to climate change suggest increases come from household demand, especially gardening and greater uptake of household appliances (eg Herrington).
- Increased risk of overflowing of urban storm water pipes and of combined sewer overflows.
- Increase of water-based vegetation growth and risk of algal blooms.
- Possible solutions to flooding include: providing more flood storage (eg reservoirs), flood relief channels to bypass vulnerable stretches of the river, channel maintenance

(vegetation control, deepening and widening); confinement of high water levels with flood embankments or walls.

Sources: Wade et al. (1999), Shackley et al. (1998), Johns 1998 after White et al. (1996)).

**Findings Specifically Related to the East Midlands**

***Impacts on Water Quantity***

The Rivers Severn and Derwent are vulnerable to single season, relatively short duration but intense droughts (Kitson 1998). This is of concern given that climate change increases the probability of summers experiencing deficits in rainfall. What is currently a 1:100 year rainfall deficit of 50% rainfall or more becomes a 1:10 year event under climate scenarios examined by SevernTrent Water (STW). Hydrological modelling of the Derwent and Trent using the UK Water Industry Research (UKWIR) method of 1998 suggests that under two climate change scenarios summer low flows will be 15% lower in 30 years time (Kitson 1998), with the other 2 scenarios still showing a reduction. More recent modelling of the Derwent system (including Ogston Reservoir and Carsington Water), supplying 17% of STW's total requirement, has been conducted using the UKCIP scenarios. Two of the climate scenarios show a loss of around 10 mega litres per day (Ml/d) over the next 20 years which will need to be added to the programmed licence reductions (Kitson 1999) (and again the other 2 scenarios still show a reduction). Beyond that, "yield losses become more serious and our River Trent scheme really starts to play an even more vital part in our solutions for the East Midlands" (ibid.). The use of the upper Derwent valley reservoirs for water storage is thought by the Environment Agency to have reduced river flows, in turn affecting the brown trout populations. Clearly, this and related problems, could become exacerbated by less summer rainfall.

SevernTrent Water's studies show quite different results from that of other water companies (such as North West Water and Anglian Water). The latter have shown a decrease in yields using the UKWIR method under certain scenarios, but an increase in yields for other scenarios. This consistency across the four scenarios examined by STW perhaps lends some greater confidence to the finding of a reduction in yields, though it should be noted that four scenarios from a single climate model is still a small number of scenarios to test. Results from one of the statistical downscaling scenarios generated in this report (Chapter 4) suggests a net annual *reduction* in precipitation. Use of this scenario in water resource modelling would clearly indicate a much greater reduction in the deployable yield. The reasons for this different projection need to be more thoroughly examined as do the disadvantages and benefits of a statistical, as opposed to a more physically-based, modelling approach.

Recent modelling of the Sherwood aquifer has produced a somewhat unexpected result which is that the cumulative amount of recharge over the next 25 years compared to the baseline is likely to increase under all four UKCIP scenarios (STW 1999). The gain is up to 1 meter. On average, groundwater levels increase progressively with the different scenarios – up to 2 meters (from a 2% increase in recharge for the low UKCIP scenario by 2050s, to a 13% increase for the medium-low UKCIP scenario by the 2020s). In some areas, however, there is a decline, eg in the area just north of Nottingham, near to Mansfield and Worksop (due to land-use, namely forestry which has a high evapotranspiration rate) and these areas will need support from the River Trent scheme (Kitson 1999). The reduction in these areas is rarely greater than 1m (up to 8%). The higher groundwater table improves baseflow in most rivers, eg the River Maun can expect 1 to 2 Ml/d additional riverflow under most conditions. We once again note the proviso that the UKCIP scenarios do not indicate whether there is a change in frequency of droughts on a seasonal to yearly frequency, which could clearly have major implications for aquifer recharge.

Turning to demand, STW's assessments suggest that the peak week factor for unmeasured water consumption will rise from a 50% increase (compared to an average week) to an 80% increase as a consequence of climate change (from 70% to 120% for peak day demand). Increasing use of meters will curb this increase, however, from 30 to 40% (weekly) and 40 to 70% (daily). STW has one of the lowest unit levels of leakage in the UK and low per capita consumption Figures. Over the last 3 years, 300 Ml/d has been removed from the supply need. Whilst STW has a similar number of customers and demand to Thames Water and North West Water, it has a much smaller baseline distribution loss (281 Ml/day compared to 466 (NWW) and 679 (Thames) Ml/day for 1998) (Environment Agency 1998). In terms of domestic meter penetration, as of 1998 STW had achieved 12.7% metering of households, compared to 6.9% for NWW and 7.9% for Thames. Note, however, that STW is still a long way behind Anglian Water, with 32.3% penetration (ibid).

Spending on demand management has increased from £60m in 1994/5 to £120m in 1997/8. STW considers that there is little prospect for demand reduction beyond what has already been achieved. The demand forecast is flat for the next 30 years. However, the loss in overall supplies from climate change is expected to be around 15% (Kitson 1998). The key strategic option for STW is to transfer water from Birmingham groundwater to the River Trent. The Central Rivers Project intends to store excess groundwater from Birmingham, diverted via the River Tame, in gravel pits near the River Trent for transfer to the East Midlands. STW may have a strategic role to play at the national level in transferring water from the North and West to the South and East if a national water grid is established and if climate change requires large-scale transfers. “The value of a large interlinked infrastructure asset is also clearly critical to reliability in the light of future uncertainty where the Severn Trent Region could well be at the centre of water transfers between the wetter north and west, and the drier south and east” (Duckworth 1999). Maintaining high water quality in the main rivers used for water transfer would be critical to the success of such a scheme. The company notes that there are political obstacles to water transfers at present. It notes that there was an ‘enormous outcry’ in the drought of 1995 because water was being transferred from the East Midlands into Sheffield, under a long-standing bulk supply agreement (Duckworth 1999). Other options such as new reservoirs are unlikely to be acceptable until the utmost has been done on demand management and on water re-use and recycling. However, given that the last major reservoir to be constructed in the UK, Carsington Water, took 30 years between conception and release of its first supply, a long planning time horizon is clearly necessary.

It should also be noted that there is a managerial difference in approach between ensuring sufficient resource on the supply side and aiming to reduce end-user demand. There is a tendency for water companies to prefer action on the supply side because they perceive that they have greater control over water further up the supply-chain. When it comes to demand management, the companies have to rely upon changes in the behaviour of consumers which the water companies perceive as less predictable and possibly irreversible, in which case water shortages could arise in the future, perhaps unexpectedly. However, many other commercial sectors have experience with working with end-consumers and rely upon reasonably consistent and reliable consumer behaviour in aggregate. Hence, the aforementioned perception may arise in part from all the water companies relative lack of experience in managing consumers' responses to demand management and reduction relative to supply-side management (where companies have traditionally focused their efforts).

***Flooding of Sewage Systems***

STW has expressed the concern that increased rainfall would create an increase in urban run-off which could not be accommodated in the storm sewer system, resulting in wide-scale flooding. The Hadley Centre GCM indicates an increase in the frequency of the more intense precipitation events. There are also events of an even higher intensity than the most intense rainfall episodes in the current climate (Bridgeman and Gregory, 1999). Intermittent discharges from the sewerage system, or CSOs, are likely to be more common under more intensive rainfall events. The company posed itself the following question: 'Can the Company's nineteenth century infrastructure cope with twenty-first century storm events'? (Bridgeman and Gregory, 1999). Altogether STW has 52,000 km of pipework! This existing network is designed to current accepted standards. Any new or replacement sewers must be designed to the standard which will provide an adequate level of protection from flooding in a changed climate. It is no longer obvious that the use of historical data on return frequencies of rainfall events is reliable. At the same time, increasing the capacity of the sewerage system can be incredibly expensive to the company in terms of capital investment. Increased turbidity of water due to intense rainfall and flooding can also cause water treatment works to close down. As Brian Duckworth, STW MD notes: "Just imagine having to deal with the PR of not being able to supply water because it's raining too hard" (Duckworth 1999). Enhanced water treatment to overcome turbidity may be expensive.

STW has undertaken a research project in collaboration with the Meteorological Office to attempt to quantify the changes in the design specifications of the sewerage system which may be required. Initial research (by the Institute of Hydrology) suggested that if the rainfall regime in London was transferred to Nottingham, and assuming that the rainfall regime between the two areas reflects the differences in mean temperature, then current return period would be expected to halve, or 'troublesome rainfall would occur twice as often!' (Bridgeman and Gregory, 1999). The STW / MO project will produce changes in the seasonal average rainfall over the ST Region in the 2020s, 2050s and 2080s. The changes in the probability distributions of rainfall and associated return period amounts for extreme rainfall events will then be examined. A method for inferring rainfall on an hourly basis from changes in daily, 6 hourly and 3 hourly rainfall taken from the climate model has been produced. Armed with these results, and with error bars associated with different scenarios, STW will aim to specify the appropriate conditions for the sewerage system under a changing climate.

***Water Quality of Rivers and Groundwater***

The Environment Agency has noted an improvement in the chemical quality of rivers, but has suggested that the increasing tendency to low flowing sluggish rivers with lower dissolved oxygen levels and increasing amounts of algae may be off-setting the improvements from a reduction in chemical inputs. In the East Midlands specifically, the Agency suggested (1999) that recent slowdowns in the improvement of river quality may be due to the low river flows and high temperatures experienced in the last 3 years. A first-cut analysis of river temperature data in the East Midlands indicates that mean temperatures have been increasing, especially in the lower, slower-moving lengths of the rivers (D.Hawley, pers.com., 2000). Chapter 4 notes that there is evidence that the trend towards recovery from acidification in the East Midlands has slowed, or even reversed, during the alternating summer droughts and especially wet winters of 1988-1990. The enhancement of favourable conditions for eutrophication arising from higher temperatures may, however, be a more important factor influencing water quality than the lack of dilution effect (Hawley, ibid). Nevertheless, a reduction in rainfall levels may require the Environment Agency to recalculate River Needs Consents (RNCs), which could result in tighter standards being applied to river abstraction licenses. The Environment Agency also note that there is a risk of a rising water table affecting the quality of the water which is located in the Jurassic Sandstones Aquifer from the coal measures which lie beneath it in Nottinghamshire. Water from abandoned mines may contaminate surface and aquifer water if more rainfall occurs.

The rapid drying out of peaty upland soils during drought has implications for water supply as Tiping (1998) et al have found with their experiments on upland soil. They found that the waterlogged peaty soils export more dissolved organic matter (DOM) after a period of warming and drying, hence the increase in water colour following droughts. The DOM can bind and transport pollutants which to be removed from the water before domestic or industrial use. The problem of water colouration from the Peak District catchments was noted during the workshops. To remove the colour, which is required under EU legislation, is an expensive chemical operation for the water companies. A further issue for upland water catchments is the risk of more upland fires as a consequence of climate change. One fire in the Peak District cost the water company £70K to put out and results in the need for greater treatment of the water used for public supplies, since the water contained more soot particulates.

The vulnerability of many aquifers in the Region to pollution is regarded as being ‘high’ to ‘intermediate’. This may make them particularly vulnerable to climate change impacts.

***Riverine Flooding Issues***

As noted in Chapter 3, 15% of the East Midlands would be vulnerable to a 1:100 year flood event if no flood defences were in place. The major rivers are all vulnerable to flooding: the Trent, Derwent, Nene, Welland and Soar. The floods of April 1998 affected the following catchments in the East Midlands: Nene, Ise, Soar, Wreake and the Smite (Bye and Horner, 1998). In total 5 people died from the April 1998 floods and economic costs are well in excess of the £350 million estimated in 1998. One of the worst affected places in the East Midlands was Northampton and a case-study follows. (The reader is referred to the Bye and Horner report for more general information on the Easter 1998 floods).

**Case Study: The Northampton Flood, April 1998**

Northampton has a long history of flooding, but defences built in the 1940s were successful prior to Easter 1998. Computational modelling was conducted in the 1980s and early 1990s which concluded that the defences would protect against a 1:100 year event. However, the flood data used to construct the model was based on a return frequency of 18 years, which is clearly inappropriate (Bye and Horner 1998). Investment plans were underway to provide an improved telemetry linked rainfall and river flow monitoring system but this had not been implemented by April 1998. "Arrangements for direct warnings to the public were not in place at Easter because of the assessed low risk due to the presence of the defences and the Agency's policy to use its limited resources to warn areas at greater risk" (ibid., 1998:12).

A further problem in Northampton was confusion over who had responsibility for issuing flood warnings. Northampton Borough Council (NBC) had agreed with Anglian Water that the latter would pass on Heavy Rainfall Warnings to the Council, who would then monitor river levels and erect appropriate barriers. The Environment Agency was unaware of this arrangement and the barriers appeared not to be required due to new development. Bye and Horner comment that the monitoring system in place was not designed for flood monitoring and was overwhelmed. Forecasting models did not take into account the fact that upstream reservoirs were full prior to the storm, which significantly increased run-off of water downstream. Some lengths of the defence system were missing or in poor condition. "The consequence of these defence deficiencies would have been the earlier onset of flooding and, possibly, more extensive and deeper inundation than would otherwise have occurred" (ibid. 1998:13). The flood defence walls and embankments were substantially overtopped. The poor state of repair of some drainage systems and water courses probably added to the duration, extent and depth of flooding (ibid.). For example, there was a partial blockage of the river by a semi-submerged houseboat.

Two lives were lost in the floods and approximately 2500 properties were inundated. Several thousand people were affected during the late evening and night of 9/10$^{th}$ April. Power supplies were cut off and the NBC's main depot was flooded, which along with flooding of the roads reduced the ability of the authorities to respond to the emergency. There has been substantial development of the flood plain at Northampton in the post-war period. Whilst this has been accompanied by development of flood detention reservoirs, the latter became overwhelmed by the flood due to the storm severity exceeding their design criteria.

***Meteorological background to the floods***

The rainfall affecting Northampton was exceptional, which turned April 1998 into one of the wettest on record (Spellman 1999). The independent review has confirmed that the floods were, in many places, the most severe ever recorded (Bye and Horner 1998):

*"persistent heavy rain on already saturated land caused rivers to rise at rates twice as fast as previously experienced, to levels as high or higher than any on record. The speed and intensity of flooding was therefore without precedent in many areas" (Bye and Horner 1998).*

Hydrological and hydraulic studies suggest that the annual probability of the April 1998 event is less than 1% and probably 0.7%, or between 1:100 and 1:150 year return frequency, though there is uncertainty about these estimates because of a lack of reliable recorded data.

The greatest proportion of rain came from 8 hours of *moderate* rainfall, as opposed to a short intense storm. However, not all previous flood events in Northampton have been a result of prolonged winter spring rainfall: at least two previous episodes were a result of thunderstorms (Holt 2000). With speculation that the strengthening of the North Atlantic Oscillation (NAO) will increase rainfall in some British locations, it was found that there was no correlation between high rainfall amounts and the NAO index. In the case of Northampton, slow moving or stationary depressions, not related to a high NAO index, are seen to be responsible for the high rainfall amounts (Spellman 1999).

### *Consequences of the flooding*

Much of the following information was obtained from the stakeholder workshop held in Northampton in April 2000.

- Post-traumatic stress (PTS) has apparently occurred at a very high level as a consequence of the flooding. On-going research by Flood Alert is attempting to characterise the PTS more accurately. Stress is experienced by many of those who have to deal with complicated insurance claims. The insurance companies response to the flood was seen by some workshop participants as too 'distant' and relying too much on loss adjusters, who many customers did not find easy to work with. It was argued by some that a more co-ordinated, 'on the ground' response by the insurance companies working together would have been more 'user friendly' as well as reducing the costs of claims by allowing discounts on bulk orders and larger contracts with building firms.

- It was noted that the new improved flood defences for the flooded district of St. James' - which will protect the town from a 1:200 year flood event - had not yet been built as of Spring 2000. The scheme was scheduled initially over 6 years, but pressure from the community had reduced this to 3 years. There was some frustration about the delay in starting the work and the risks that it entailed. There are many procedures (including consultations) which have to be completed before the work could start, however.

- Some workshop participants proposed that insurance companies should club together to put forward the £10 million necessary to undertake the work as a loan to government. The insurance industry believes, however, that it is the responsibility of MAFF, EA and LAs to pay for flood defence.

- New supplementary planning guidance (PPG25) is now in place which provides guidance to developers on how to assess the implications for flooding of proposed development. Since PPG25, developers are now required to produce an assessment of flood risk from development, rather than it being the responsibility of the planning authority to demonstrate a flood risk. The SPG states that discharge from any new development should be no greater than that from the same site if it were to remain a green field site (Environment Agency 1999).

- Sustainable Urban Drainage Schemes (SUDS) were recommended in the above report, including simple things like disconnecting drain pipes on houses from storm water storage systems, and encouraging more interception of water at the household level. Anglian Water has a new scheme whereby there is a reduction in the water rates when householders disconnect roof drainage from the sewer system. Imaginative use of storm water detention areas could also allow for habitat recreation, perhaps as reedbed.

- As a result of public consultation, 2 hour flood warnings are given in Northampton by the EA through sirens. There is also an automated voice system which goes to the telephones of people who want to be connected. A phone line is available to inform members of the public on flooding risk in Northampton.

These responses go to address the findings of the independent review of the floods that there: "were instances of unsatisfactory planning, inadequate warnings for the public, incomplete defences, and poor co-ordination with emergency services", though the report did also conclude that: "apart from specific weaknesses ….. the Agency's policies, plans and operational arrangements are sound" (Bye and Horner 1998).

***Floods and Planning***

There are difficulties in getting flood risk issues properly on to the Planning Agenda. These arise from the lack of a clear statutorily-backed system of regulation and guidance on flood plain development. Local planners in the past have been on weak ground in rejecting applications for new developments on the basis of flooding risks, even if they might privately agree with the Environment Agency's opposition. This is because of a lack of a policy platform or framework from central government, without which developers can take the local planning authority to Court if development plans are rejected. Without a strong policy framework, developers might well win in Court and the Local authority has to pay legal costs, which it can ill afford.

- PPG25 puts the onus on the developer to show that new development is not subject to unacceptable flood risk and begins to move the system more to what the EA would like to see. It strengthens Circular 90/32. The EA wishes to see development plans which have no more than a 1:100 year fluvial risk and a 1:200 year tidal flood risk. PPG25 also states that in some circumstances there should be an *increase* in the level of flood protection offered as a result of development.
- The EA in its response to the East Midlands draft Regional Planning Guidance stressed the need to guide development away from flood plains. The need for this will become more apparent if climate change does increase the flood risk.
- Received wisdom that once flood defences are installed, building behind them could increase is now discredited and will have to be phased out. However, flood defences do raise the value of protected property and land, so increasing justification for yet higher defences.
- Developers have bought up land in Northampton and environs in the expectation that it will be able to be developed in the future, so they will fight quite hard if this appears not to be the case.

***Long-Range Questions***

Several participants in the workshops questioned whether the implications of climate change could be more radical than is commonly perceived. Rather than waiting for 1:200 year flood events to occur in towns and cities in the East Midlands as a consequence of climate change, and then responding once the damage as been caused, perhaps a precautionary approach should be adopted. This would imply reinforcing existing defences to a higher standard of protection than is currently considered necessary based on analysis of historic data and hydrological modelling. There would clearly be a significant price tag attached to such reinforcements. Note, however, that where replacement of the defences is already happening, a change in the standard of protection from a 1:100 to a 1:200 year return frequency is relatively inexpensive. Hence at a minimum a precautionary approach might imply reinforcing new defences to a higher level than suggested by analysis of historical data.

The problem still remains, though, of exactly *what* level of extra protection should be planned for and implemented. This question is not readily answered even when using the existing data since there are different and equally valid methods of calculating 'return frequencies'. Very frequently sufficient long-term data is not available to produce low return frequencies with any reliability. Furthermore, some Environment Agency experts have argued that the uncertainty surrounding return frequencies means that they are not a reliable tool for deciding on standards of protection. Flood protection measures should, instead, be based on, and be able to protect against, the evidence of the worst experienced events. This strategy seems unable to account for climate change, however, unless there is some basis for including an additional level of protection in the design. An even more radical suggestion was that relocation of existing habitation from river flood plains could become necessary in future due to the excessive risk of flooding in a changed climate and the high costs of attempting to protect against it. Others argued that this approach would be problematic since so much development and habitation occurs on the flood plains. It was therefore not clear where all these people and settlements would move to.

At present, few river catchments have been explicitly modelled in order to assess how their properties might change in response to a future climate change. To conduct such modelling for all river catchments is expensive and beyond existing research budgets. The Bye Horner report identified a lack of scientific knowledge as one of the problems which led up to the April 1998 floods. Some system of prioritising hydrological and hydraulic measurement and modelling of catchments is needed to improve the scientific knowledge base.

***Land use and floods***

It is suggested that land use change apart from built development is a significant contributory factor in exacerbating flood events (Harrison and Foster 1999, Clark 2000).

- Much of the East Midlands agriculture is supported by loamy and clayey soils which are artificially drained. They are impermeable and lie wet in winter - drainage from these soils to streams and rivers is rapid and so can cause flooding. The sandy, loamy and clayey soils of much of Southern and Eastern Lincolnshire are associated with a high risk of flooding (Environment Agency 1999), which could increase under climate change.
- Arable crops such has maize or oil seed rape planted on soils liable to erosion (such as silty soils) leave the soils exposed as they provide minimal cover during their early stages of growth.
- Soil erosion and floods could be an increasing problem with the increasing amount of maize cultivated under a warmer regime.
- With the recent trend for all-year grazing on the uplands, vegetation has had very little chance to recover.
- Overgrazing in the Pennines exacerbates the impacts of extreme rainfall events: in the north Derwent catchment in the Peak District, as sheep numbers rose from 12,000 in 1944 to 24,000 in 1975 the runoff rate increased by about 25%. It is concluded that overgrazing and other forms of land management have much greater impact on the sensitivity of land to erosion than climate change itself (Johns 1998).

***Snowmelt***

- The rate of snowmelt is highest in the Pennines, rather than coastal regions. Mildness is not the greatest factor in melting but rather the amount of snow available and the windiness of high altitude areas. It was found that wind is critical (eg the Southern Uplands in Scotland, with extensive forestry plantations, have a lower rate of melting than would be expected for a high altitude location). The difference in extremes (over a period 5- 50 years) of snow melt rate vary from Waddington (Lincolnshire) where the maximum melting of snow is 8.3 mm to 15.9 mm per 24 hours, and Malham Tarn (Yorkshire Dales) where the maximum rate of snowmelt per 24 hours can be between 46.7 to 84.9 mm (Hough and Hollis 1998). This could imply a higher flood risk for the Peak District rivers under a pattern of windy mild weather following a short lived snowy period on the hilltops.

***Internal Drainage Boards***

In designing a specification for internal drainage systems, the Internal Drainage Boards (IDBs) rely upon information on the average and extreme rainfall events. The size of the drainage channels and the size of the pumps required to move water from drainage systems into the sea depend upon information on the magnitude and frequency of extreme rainfall episodes, which is likely to change in response to climate change. Hence guidance is required by the IDB on how it should revise its calculations. One IDB felt that more rainfall events had been becoming more intense in the last few years. The costs of pumping water could also increase in response to more intense rainfall events.

The IDBs have to respond to the needs of agriculture for drainage and also have a role in protecting urban areas from flooding through drainage of excess water. However, the IDBs can also store water in the drainage system during the summer. There is no point, from the IDB's perspective, in reducing water levels to lower than is necessary as it costs money to do so. This water in the summer could conceivably be used for irrigation, and also has biodiversity benefits. The IDBs are also interested in increasing the capacity of the drainage system by development of sacrificial flood plain areas. Certain fields could be designated as flood control areas and a payment would be made to the land owner equivalent to a set-aside payment. At present, such an approach is not considered to be cost-effective, but perhaps it may become so as a result of future climate change? There would also be significant biodiversity benefits for birds from adopting this approach to flood alleviation as it would benefit many wading birds and ducks (swans, widgeon, pintails, black-tailed godwits, etc.).

### 5.3.4 Biodiversity

**General Findings on Biodiversity and Climate Change of Relevance to the East Midlands**

In previous regional studies, biodiversity has emerged as one of the most important areas affected by climate change. Below is a brief summary of the key issues already identified, including recent publications.

- Impacts of sea-level rise and extreme events on Lincolnshire coastline (see under section 4.5.) - potential loss of habitats.

- Low river flows reducing aquatic habitats; lower water table limiting wetland habitats.
- Change in competitive balance of species: opportunities for some. Will species be able to migrate quickly enough? Will they be able to get through urban areas? Recent work suggests that although weeds and plants of waste land and gardens will be dispersed very effectively in the modern fragmented landscape, rare plants confined to reserves or other patches of 'ancient' countryside will not (Hodkinson and Thompson 1997).
- The growing season over Europe has lengthened since the early 1960s by 10.8 days, this is a result of earlier dates for spring leaf unfolding (6 days) whilst autumn colouring has been delayed by 4.8 days. The increase can be attributed to changes in air temperature - the data from phenological gardens occupies only a few sites where the urban heat island effect would have influenced the trends. The noted lengthening in the growing season is in accordance with satellite data from 1981-1991. The implications for increased biomass formation and accelerated tree growth are unknown as it is another factor to be taken into consideration as well as carbon dioxide fertilisation (Menzel and Fabian 1999).
- Bracken has become increasingly a problem in the upland regions of England, as afforestation has slowed. In the UK bracken cover has doubled during the 1900s and now occupies 7% of the total land area. It is currently limited to a maximum altitude of 518m above sea level (asl), but this could be altered upwards by climate change. Until 50 years ago there were more cattle grazing on the hills and trampling was enough to damage and halt progress of bracken. Sheep graze competing species such as heather and bilberries and do not trample the bracken; with moister conditions in the uplands, climate change could favour the further spread of bracken (Taylor 1997). Early drought would give heather a competitive advantage over bracken, whereas late drought would have the opposite effect.
- There is now large scale evidence of poleward shifts in the range of entire species of butterflies. It was found in a sample of 35 non-migratory European butterflies that 63% had shifted to the north by 35-240 km during the 20th century whilst only 3% had shifted south; the survey deliberately looked at species least likely to have been affected by habitat alterations (Parmesan et al. 1999). What is noteworthy is that butterflies are sensitive to temperature, and so the northward shift of species is a response to the recent trend of warmer temperatures. This northward shift is likely to continue due to the warmer temperatures under climate change.
- Migratory birds are already arriving sooner with swallows arriving 2-3 days earlier with a $1^{o}C$ rise in spring temperature. (Sparks and Loxton 1999) The range of birds has also extended northwards according to research by Thomas and Lennon (1999), who found that the northern margins of southerly species have moved north by an average of 18.9 km in 20 years. Comparisons were made between surveys in the years 1968-72 and 1988-91. It has been found that there is a long term trend for earlier egg laying amongst UK bird species, (Crick and Sparks, 1999) and that 31 of the 36 species investigated have laying date related to either precipitation or temperature. Taking the medium high scenario from UKCIP predictions, they predict that laying dates will be on average 8 days earlier for 75% of species by 2080.

## Findings Specifically Related to the East Midlands

### *Impacts of Drought on Grasslands and Species Balance*

A study conducted at the Buxton Climate Change Impacts Laboratory (BCCIL) examined the impact of the 1995 drought on vegetation. It concluded that tap rooted forbs such as Salad Burnet (*Sanguisorba minor*) and Burnet Saxifrage (*Pimpinella saxifraga*) had a clear competitive advantage over other plants. Drought seemed to act as a re-setting mechanism, restricting the progress of plants which had expanded onto shallower soils from the deeper soils of the valley bottom (Buckland et al. 1997).

In a long-term climate change experiment, limestone grasslands at BCCIL and Wytham, Oxfordshire, have been exposed for seven years to simulated summer drought, extra summer rain and winter warming (3ºC), plus combinations of warming and the two rainfall manipulations. Although Wytham is outside the East Midlands, its responses will be representative of lowland grasslands on light soils throughout England. In the main, the message for the uplands is reassuring: the vegetation at Buxton has proved remarkably resistant to the treatments, with very little year-on-year change in biomass in response to any of the treatments. Within years, extra grass growth in the winter should encourage the trend towards all-year grazing of upland grasslands. However, warm winters and summer drought have caused a slow decline in the abundance of sedges. Sedges are already confined to infertile parts of the landscape and many are threatened, so this is a worrying trend.

Changes at Wytham have been much more dramatic. Following the 1995 drought, biomass of shallow-rooted perennial grasses fell sharply in all treatments, but those also exposed to experimental drought and warming fell to only 30 % of the control value. The BCCIL's results suggest that future climate warming could see a shortage of grass in the lowlands in mid-late summer, with the growing season moving more to spring and autumn. A shortage of grazing was experienced in the drought summers of 1976 and 1995, pushing up prices for fodder. Overall, there will be less grass, with more deep-rooted perennials such as thistles and docks. There is little threat to biodiversity from changes to fertile, lowland grasslands, since such communities are normally very species-poor anyway (Thompson *et al.* 2000). Movement of the growing season towards winter will depend upon warmer winter temperatures. Grazing and harvesting of winter grasses may be limited by wet soil conditions.

Other work at BCCIL highlights the possible spread of the invasive grass *Brachypodium pinnatum* in the Derbyshire White Peak. *Brachypodium* is a serious threat to the diversity of chalk grasslands in southern England, but is currently at its northern limit in Derbyshire. Since it is very responsive to nitrogen, it is well adapted to take advantage of continuing anthropogenic N-deposition. The BCCIL's work suggests that it would take very little for *Brachypodium* to spread in the Peak District, and that its present limited distribution may owe as much to low genetic diversity as to climate.

### *Impacts upon Upland Species and Habitats*

The Peak District contains the most southerly and easterly blanket peat bogs in the UK, including the extensive plateaus of Kinder and Bleaklow – eg there are 9km$^2$ of bog at Kinder going down to a depth of 3 or 4 meters representing a huge amount of carbon. The Peak is effectively where the south-east type climate of the UK finishes and the north-west type climate starts. Hence, landscapes and biodiversity could be highly sensitive to even a slight change in temperature and rainfall. Climate change could just 'tip the balance' to make the bogs unstable. The blanket of jelly-like peat on the summits depends on relatively high and clean rainfall. Wetter winters under climate change would certainly help the bogs but higher temperatures and drier conditions result in fungal and bacterial decomposition which releases carbon. As one workshop participant noted: ‘Release of the carbon in Kinder and Bleaklow alone could affect the carbon budget of the UK’.

The impacts of climate change upon the blanket peat bogs would therefore depend on the precise balance between higher rainfall and higher temperatures. Despite extensive investigations of the competing effects of rainfall and temperature, the scientific community has not arrived at a clear answer on the net effects of climate change upon the peat uplands (for more discussion see Shackley et al. 1998:19). The peat bogs are likely to be quite a sensitive indicator of climate change.

A change in upland species could see less common species such as crowberry becoming somewhat more frequent, whilst purple moor grass may also expand. Other rare montane plants that reach their southern limits in the Peak District, eg cloudberry (*Rubus chamaemorus*), Alpine Lady's Mantle (*Alchemilla alpina*) and Dwarf Willow (*Salix herbacea*) are more likely to decline, especially since they are right at the limit of the south easterly distribution of these species in the UK. In a warmer climate, bracken grows earlier, but it is a species which is very sensitive to frost, so could be disadvantaged by later frosts interspersed with milder winters.

Plants such as **Jacobs Ladder** (*Polemonium caeruleum*) occur on steep northern-facing limestone dales at over 20 sites. The Peak District contains virtually all of the UK’s colonies of this attractive species, the nation’s only representative of the Phlox family. They favour the cool and damp conditions of such dales and may disappear as warmer and drier weather occurs due to climate change. The species has no where else to go in the UK and can only survive on northern-facing slopes in the Peak. The **Stemless thistle** (*Carlina acaulis*) is absolutely at its northern limit in the Peak. It does not produce seeds in the Region because the seed heads get too wet and cold and do not ripen though seeds were produced in the drought year of 1995. If this species (which is common in areas such as the South Downs) starts to produce seed, then this would be a good indicator of climate change (provided that the effects of management were taken into due consideration).

***Upland Fires***

An increased risk of **moorland fires** arising from climate change is a major issue for the Peak District. Such fires could lead to the replacement of heather moorland by grass, with serious implications for soil erosion and grouse-shooting. There have been 30 to 40 fires on the National Trust estate in the High Peak in the past decade – about a dozen of which have been classified as ‘major’ fires. Approximately one third of fires are caused by visitors’ cigarettes, whilst another third are heather management fires that have gone out of control. Fires have a direct impact upon plant communities. An even greater problem is when fires get down into the peat causing large areas of erosion which are very difficult to re-vegetate, and which add to water colouration and associated treatment problems. Acidic rainfall tends to erode the bare peat yet further with large amounts being washed away. More intensive rainfall under climate change could accelerate this process yet further.

The Peak District National Park Authority has done much work on educating visitors about the risks and hazards of fire. Work is also proceeding on how to respond more effectively to fires when they do occur. Schemes are also being undertaken in the Peak on how to restore vegetation after fires. The problem of re-vegetation was described by the National Trust, however, as 'quite immense'. By contrast, the issue of footpath erosion is relatively minor, though remains important in specific locations such as Kinder.

***The Threat to Wetlands from Water Abstraction***

Land drainage in the Lincolnshire Fens has nearly destroyed the huge area of wetlands which once occurred, including habitats such as marshes, reedbeds and fish ponds. A new initiative - Wet Fens for the Future - is aiming to re-create wetland habitats in Fenland. A recent report from the East Midlands Wildlife Trusts (Danby et al. 2000) has highlighted the detrimental impact of water abstraction upon wetland habitats in the region, especially in the two main aquifers: the Sherwood Sandstone Aquifer and the Chalk Aquifer in Lincolnshire. Part of the rationale for the study is the observation that non-statutory sites (ie non-SSSIs) are not part of remediation schemes arising from over-abstraction. The Sherwood aquifer supplies a large amount of the potable water required by Nottingham. Water levels declined for a century before stabilising in the last 20 years. The actual annual abstraction in four of the six areas of the aquifer is less than 80% of the estimated recharge, but there is up to 45% over-abstraction in the other two aquifers. Overall, estimated recharge for the whole aquifer is about the same as the water abstracted. Modelling suggests, however, that at least 35% of the annual recharge should not be utilised in order to guarantee the base flow of rivers and maintain the water table. Likewise, abstraction from the Lincolnshire chalk aquifer is about the same as recharge, meaning that there is scarcely enough water to supply natural springs. The results of the report are summarised below.

**Table 21 The Impacts of Water Abstraction on the Region's Wetlands**

| Number of Wetland Sites Affected | | Cause: Over-Abstraction | Cause: Seasonal Drying | Cause: Other (specified) | Quality of Evidence | Examples |
|---|---|---|---|---|---|---|
| Significantly | 7 | 3<br><br>(1 joint) | 1 (joint) | Drainage (1)<br>Flood alleviation (1)<br>Agriculture (1)<br>Management (1) | Quite good | Oxton Bogs (Notts)<br>Water Hills (Lincs)<br>West Haddon Meadows (N'hants)<br>Ashby Parva Meadows (Leics) |
| Suspected | 9 | 5<br><br>(4 joint) | 4<br><br>(4 joint) | Breach of pond bed (1)<br>Flood alleviation (1)<br>Unidentified (2) | Reasonable | Black pool (Notts)<br>Oxton Lakes (Notts)<br>Donnington March (Lincs)<br>Thoresway Bog (Lincs)<br>River Lymm (Lincs) |
| None | 2 | 1 (joint) | | Gravel extraction (1 jointly)<br>Succession (1) | Quite good | Sutton Gravel Pits (Notts)<br>Forbe Hole (Derbys) |
| Total | 18 | 9 | 5 | | | |

Source of data: Vanishing Wetlands, Danby et al., East Midlands Wildlife Trusts (2000).

The results indicate that water abstraction is the most common reason for suspected and significant damage to wetland habitats. To give some specific examples, Dover Beck in Nottinghamshire was a groundwater fed watercourse which used to flow into the Oxton Bogs, which were to be designated as an SSSI. However, a drop in groundwater decreased the flow of the Beck at source which fractured the bed allowing percolation of water to the water below. As a consequence the ecological value of the bogs was significantly reduced, with the loss of 80 species, and the site was not designated as an SSSI. The Environment Agency has recently attempted to restore the flow by relining the beck and feeding it from a specially sunk bore hole. At Ashby Parva Meadows in Leicestershire, a drainage ditch was dug across the site with the aim of reducing the water table. The formerly wet meadow has consequently lost some of its wetland species such as marsh marigold and populations of ragged robin and great burnet are in decline. Likewise, the River Idle / Mission Levels were once an extensive area of seasonally flooded wet grassland rich in biodiversity, including nationally rare species such as the Rannoch rush and fen violet. The Levels were converted to arable farmland following the installation of a major new flood defence scheme (East Midlands Regional Biodiversity Forum 1999). A further example where the water table has been lowered to facilitate agriculture is Narborough Bog in Leicestershire - despite the fact that the site is an SSSI (ibid.).

The East Midlands WLTs report considers that agricultural intensification is the greatest threat to wetland habitats. The Fenlands have of course been extensively drained. Even in the last 15 years, some observers have seen a significant decrease in aquatic flora in the ditch system of the Humberland levels (due to change in ditch management and increased input of fertilisers). Even in the White Peak there has been a 50% decline in ponds in the last 15 years, principally due to lack of pond maintenance. Flood alleviation projects frequently aim to move water through a site more rapidly by straightening and deepening of channels. However, in so doing, the water table drops somewhat and less flooding of surrounding lands occur, therefore reducing wetland species and habitats. At Donnington Marsh in Lincolnshire, for instance, the River Bain which passes through the site has been canalised, which has reduced the flooding of the area. The consequence has a decline in the richness of species represented, especially marsh herb species.

Inappropriate management includes enriching waters for fishing or waterfowl, water sports, use of weed killers and tree planting. At 'Pond' in Leicestershire, 41 species of wetland plant were recorded in 1979, together with amphibians, water voles and invertebrates. The land owner planted trees on the pond's edge and kept excessive numbers of ducks. As a result, enrichment of the water and excessive shading led to loss of most of the species to be replaced largely by algae.

Mineral extraction can adversely affect wetland habitats. At Benniworth Haven in Lincolnshire, for example, gravel workings nearby are pumped to remove water and it is suspected that such pumping is draining the wetlands. Restoration of mineral extraction sites also offer great opportunities for wetland restoration, as at Sutton Gravel Pits where 91 wetland species now occur. Many other excavated gravel pit sites which are now important nature reserves could be mentioned (East Midlands Regional Biodiversity Forum, 1999:12). Rutland Water, although only 15 years old, has become an internationally-recognised site for wildfowl, with more than 20,000 birds passing through or resident (ibid.). Mining subsidence in the Erewash Valley (Derbyshire / Nottinghamshire border) has created new pools and marshes. Flooding of old mineshafts, on the other hand, has led to out flows from mineshafts of acidic water with high sulphate and iron content, which can have severe effects upon aquatic systems. Finally, invasive and alien species include Australian swamp stonecrop (*Crassula helmsii*) which is highly effective at invading ponds and wetland habitats, American Mink (thought to depress water voles and ground-nesting birds) and the signal crayfish, which is replacing the indigenous white-clawed crayfish (eg River Leen in Nottinghamshire). Japanese knotweed, Himalayan Balsam and pennywort can also be mentioned as alien and invasive species. The Giant Hogweed attacks flood defences when they are exposed during periods of low water levels.

### *The Possible Impacts of Climate Change on Wetlands*

Detailed site-specific hydrological and biological modelling would be required to evaluate the impacts of climate change upon wetland habitats in the East Midlands. If socio-economic conditions and practices remained the same, it could be suggested that the slight net increase in annual rainfall would be beneficial, though increased evapotranspiration in the summer might offset any benefits. SevernTrent's hydrological modelling suggests that the Sherwood Aquifer will benefit in terms of recharge under all UKCIP scenarios. The implication is that baseflow to streams and rivers and wetland habitats will improve and hence benefit such sites. The UKCIP scenarios do not, however, assess the change in seasonal and yearly variability of rainfall, and hence do not include what could be amongst the most significant impacts of climate change upon biodiversity, such as more extended and back-to-back droughts. The droughts of the late 1980s and early- to mid-1990s led to the disappearance of wetland species in Lincolnshire, such as the sundew which was lost from 7 to 8 sites, and butterworts, lost from 3 to 4 sites. Other species which prefer hotter weather have done better in Lincolnshire, such as the Lizard Orchid. Wetland birds' nesting sites become more vulnerable to predation as a result of drying out, as was witnessed for moorhens during the 1995 drought. Higher water temperatures could influence the balance of species in wetland habitats, as could changes in water quality due to a change in agricultural practices under climate change. Greater recreational use of wetland areas due could result in more stress.

Change in the distribution of rainfall could also have an effect upon coastal amphibians such as the natterjack toad, which have been reintroduced to Gibraltar Point National Nature Reserve (NNR) in Lincolnshire. The natterjack toad relies upon temporary pools which form in the dunes in winter and spring, drying out in the summer. If the pools were to remain full throughout the year, or were to dry out too rapidly in the spring, then the natterjack toad could be threatened by competition from other toad species, or from loss of habitat.

Clearly, the impacts of climate change depend much upon how land management, abstraction and flood alleviation practices change in the future. For example, a reduction in drainage of water from the land would help to maintain wetlands. A change from pine plantations to the natural wet heathland would allow wetlands to re-emerge throughout the Region. This has occurred at one site in Lincolnshire and consequently the sundew has made a come back there. However, given the additional uncertainty that climate change poses for biodiversity and the wetlands, it could be argued that management practices should aim as far as possible to increase the resilience of ecosystems to change by reducing additional stresses such as those mentioned above. A further conclusion is that more knowledge is required on the characteristics and biodiversity of wetlands. There is a general lack of knowledge of where springs and wetlands occur and what biodiversity depends on them.

### *Impacts upon Other Species*

New species will occur in the East Midlands as a consequence of climate change. Little Egrets and Dartford Warblers are now moving into the Region, but their success will depend upon availability of habitat (pers.com., RSPB, February 2000). For instance, some buntings do better in warmer summers, but the primary factor determining their success remains availability of habitat. The knock-on effects of a change in agriculture due (in part) to climate change are also likely to be significant: for example sowing winter crops earlier would affect availability of habitats. The East Midlands could gain some southern species if coniferous plantations were replanted with the native heathland, though species might need artificial reintroduction. The RSPB is actively developing appropriate habitats for the Bittern at Langford Lowfields in Nottinghamshire, using land currently owned by Tarmac.

Bird species may be vulnerable to increased variability if it were to mean that breeding and nest-building were to take place earlier in the year, but then if a cold snap were to take place in late winter / spring, threatening those birds. A cold spring and wet summer can chill and starve chicks resulting in as much as a 15% drop in populations. Summer flooding is generally harmful to ground nesting birds, but more winter flooding would be beneficial.

Birds in nature reserves are also vulnerable to a change in recreational patterns and pressures. At Gibraltar Point, for example, the wading birds' behaviour is strongly coupled to tidal patterns: as the tides go out in the morning, so the birds leave their roosts to go and feed on the exposed muds. This happens to be at the same time as most of the visitors are arriving. Likewise, most visitors tend to be leaving as the tide comes back in and the birds come back to shore to roost. If, however, visitors began to arrive earlier or to leave later, perhaps in order to avoid the hottest weather, then the birds would be much disrupted. With 180,000 visitors a year to Gibralatar Point reserve, much of it spill-over from Skegness, a change in recreational patterns would not be trivial.

Amongst insects, a large parasitic wasp the bee wolf, was noted at Gibraltar Point in the last few years, as was the European Corn Borer, potentially a major crop pest. Loss of species from the East Midlands is not necessarily 'compensated' by their occurrence elsewhere in the UK, since the populations which occur in the Region demonstrate particular and distinctive genetic and phenotypic characteristics eg the natterjack toad.

### 5.3.5 Cultural Heritage

**General Findings on Cultural Heritage and Climate Change of Relevance to the East Midlands**

With a great abundance of archaeological and historical sites, many parts of the UK have already identified sites likely to be vulnerable to climate change. The key impacts are:

- Impacts on archaeological sites: exposure, erosion, etc;
- Impacts of sea level rise/coastal erosions on historic sites and buildings;
- Impacts upon valued landscapes;
- Impacts on parks and gardens: plants less able to cope, water shortages, decline in water quality;
- Forest fires;
- Impacts on building infrastructure;
- Impacts of increased tourism due to climate change upon historic sites;
- Loss of pollen and other records by drying-up of archaeological sites;
- Impacts of farm winter reservoir construction (a potential option for adapting to climate change) upon archaeological sites;
- Some historic buildings were built on timber piles or rafts which are stable as long as they are kept wet. Structures such as timber framed and cob-walled buildings may behave differently under differing temperature and humidities, and their internal fittings could be vulnerable to building movement. Other concerns are increased risks of fire with dry summers and incidence of fungal and insect problems such as dry rot and house Longhorn beetle under a warmer climate.

**Findings of Specific Relevance to the East Midlands**

The Lincolnshire coastline contains several historic sites that could be lost as sea-levels rise. Vulnerable sites include the following:

- A bronze age salt extraction facility was recently discovered in the intertidal zone near to Ingoldmells, only the second to have been found in Lincolnshire;

- 16th and 17th Century wrecks of boats, fishtraps and fisheries located in the intertidal zone at various places along the coastline;
- A pre-historic forest consisting of peat and tree trunks which is about 3000 years old south of Skegness.

It is felt that little can be done to reduce the vulnerability of these sites to sea-level change and extreme events. Hard defences would clearly be an inappropriate response for most archaeological resources. In terms of impacts upon inland sites, climate change and the overuse of water resources and drainage schemes may have been having an impact upon the preservation of buried remains in the East Midlands. Restoring wetlands would assist in reducing vulnerability of sites and artefacts to drying-out. A major problem in assessing the impacts of climate change upon cultural heritage is a lack of clear empirical evidence and more research in this area would be helpful (pers.com., Robert van de Noort, English Heritage, July 2000).

### 5.3.6 Leisure and Tourism

**General and Specific Findings on Leisure and Tourism and Climate Change of Relevance to the East Midlands**

- The hot summer of 1995 led to an increase in tourist spending in the UK, showing a potential in warm dry summers for more recreational and sporting activities in the UK. Family groups and short break holidays are believed to be the most climate sensitive according to regional tourist boards, with British holidaymakers taking more spontaneous decisions about when and where to travel (Giles and Perry 1998).
- Hotter, drier summers are likely to increase use of regional resources by local inhabitants.
- Tourism in the Peak District is less weather sensitive than the coast although sunny weather is perceived as boosting visitor numbers especially in the spring when the first sunny days occur.
- It is unclear, however, whether there would be a significant increase in commercial tourism, eg short- or longer breaks from people within or outside of the Region. This would partly depend on what happens to the climate in what are today the more popular destinations (such as the Mediterranean).
- More people are expected to visit the coast if indeed there are longer drier periods with higher temperatures. If it is a sunny hot Sunday then people are attracted to coastal resorts. The weather can also determine whether they visit for a day or stay for longer.
- Social patterns are already changing such that resorts are now being used much more all-year-around, eg caravan sites. All year round tourism is increasing due to there being more leisure time, significant investment in attractions, and attitudinal change, whereby people are now prepared to do outdoors and leisure activities in the winter and autumn. This trend is likely to be reinforced by climate change.
- With the decline in farming in Lincolnshire, the local economy is more than ever locked into tourism. Indoor, all-weather attractions have also been further developed which will

help tourism to develop even if climate change implies greater weather variability. An increase in use of facilities all year around is very important in economic terms. If visitor numbers in the winter to sensitive nature reserves such as Gibraltar Point should increase, however, then there could be negative impacts on the birds - especially as this is the most important time for many migratory bird species.

***Environmental Pressures from Tourism***

Increasing visitor numbers obviously puts greater pressure upon infrastructure and environmental systems. The lack of good public transport to resorts such as Skegness and Mablethorpe means that the visitor has little alternative to use of the private car. The 27,000 caravans around Skegness put a great demand upon sewage treatment and this has required the installation of a new treatment works. Hitherto, the caravans have been excluded from having to pay a license fee to the local authority to assist in the provision of services and infrastructure. As Skegness has aimed to comply with the EU Bathing Water Directive and maintain its “Blue Flag” status it is increasingly likely that the caravan sites will make some contribution to the costs.

The Peak District is subject to numerous other pressures from tourism. It is the second most visited national park in the world receiving on average 22 million visitors a year! It is felt by the Peak District National Park that the National Park cannot sustain many more visitors – it is at the maximum or at least not far off. The ecosystems of the Peak were perceived to be highly fragile and already over-stressed, eg in areas like the peat bogs of Kinder Scout. Hence, the issue raised at the workshops was how to discourage even more day trippers into the Peak due to climate change. At the same time, the economic importance of tourism to the Peak was acknowledged and it was proposed that a compromise would be to turn more day trips into longer-staying visits. In that way, impacts arising from transport would be reduced, whilst the economic benefits to the area would be maximised.

It was noted that the tourist season in the Peak is also beginning to lengthen – more people are choosing to visit in the late autumn and late winter. The ‘greys’ are the growing part of the market and older people do tend to be more influenced by the weather. So, warmer and better weather could combine with greying of the market to increase tourism (visitor numbers and duration of stay). This could further increase pressures, though much would depend on the balance between day and longer-stay visitors, and the distribution of visits throughout the year.

***Mitigation of tourism pressures: Regional Distribution of Tourism***

Pressure upon the Peak and coastline may come from the southern part of the East Midlands region, in addition to visitors from other regions. Tourist authorities could try and move tourism into the shoulder periods. It may be that the coastal resorts can take more visitors than the Peak, so a strategy could be devised to influence destinations. Spare capacity in the Peak District may only be available at certain times of the year. A regional strategy may also involve taking pressure off the Peak and coastline by developing destinations in, eg Nottinghamshire. Already, county and district councils have collaborated in developing country parks and visitor centres in Nottinghamshire, eg at Sherwood Park, to try and divert tourism pressures. This also brings local economic benefits.

***Public Information on Climate Change***

It was suggested that the visitors to the Peak may be interested in learning more about climate change and its possible impacts. One output of the present study could be information and interpretation boards and materials.

***Changing Leisure Patterns to the 2050s***

How people consume their leisure time may be very different in the future – so it is difficult to analyse the impacts of climate change given that it is only one factor amongst many eg what sorts of technology-based new tourism markets may emerge?

### 5.3.7 Transport

**General and Specific Findings on Transport and Climate Change of Relevance to the East Midlands**

- A reduction in the number of frosts would reduce delays to railways from icing of points or electrical equipment and roads will require less road salt (UKCCIRG 1996). Less of the de-icing agent glycol might be required at East Midlands airport, reducing the amount of the pollutant which runs off into the River Trent.

- Higher and more intense rainfall, however, could result in more pollutants being transferred from roads to water ways and habitats.

- The risks to transport from climate changes would include increased heat stress to minor road surfaces and railways. Heat causes maintenance problems for road surfaces and track buckling for railways.

- With more cyclists on the roads in a warmer drier summer like 1995 it was noted that cycle and motorcycle accidents had increased (Thornes 1997).

- High winds affect both road and rail, with wind blown trees blocking routes and exposed bridges being closed to high sided road vehicles. Railways with overhead electrification are affected by high winds as are shipping and air travel.

- Flooding can cause localised problems (including landslides) but unless the floods are extreme, are judged to be less significant than the disruption brought about by snow and ice.

- Inland waterways (of importance mainly to the tourism and leisure sectors in the East Midlands) may also face impacts from climate change such as restricted flows and changes in river flow regimes effecting sedimentation and hence maintenance (UKCCIRG 1996).

- The relationship between weather and road accidents was investigated by Edwards (1999). Edwards states that the vast majority of road accidents occur in fine weather, Thornes (1997) points out that in 1995 two thirds of road accidents occurred on dry road surfaces. Weather can influence the volume of traffic and therefore the risks per unit of travel, and so the number of road users exposed to risk also increases. In fine weather, increases in holiday traffic influences accident frequency because of drivers' unfamiliarity with minor roads in resort areas - Cornwall and North Wales record higher rates of accidents in summer; it is not known whether this finding is replicated in the Peak District and the East Coast resorts. Fog, although widely feared, accounts for only 2% of annual accidents in Northamptonshire, one of the counties with the highest rate of fog incidence.

- Fine weather can become a problem for road safety if temperatures become excessively high. Stern and Zehavi (1989) conducted research on a road affected by very high temperatures (above 24°C) and found that the risk of an accident increased during hotter weather. The research was carried out on a desert highway which did not have obstacles such as parked vehicles and trees, and found that most accidents were caused by cars running off the road or turning over - a result of heat stress on driver concentration.
- Ports and harbours can be disrupted by coastal and river flooding, by rising sea-levels and by extreme winds. Changed siltation patterns due to climate change can cause problems for ports. There are no large ports in the East Midlands (excluding north Lincolnshire). However, ports such as Boston and Fosdyke are potentially vulnerable to a change in sea-level height and storm surges.
- Warmer summers could increase traffic pressure on already busy roads to resorts like Skegness and the Peak District, in addition to roads throughout the district as more people head out of cities during hot dry summers. Skegness has problems with congestion and parking. Public transport in Lincolnshire is currently undeveloped.

### 5.3.8 The Impact of Climate Change Upon The Built Environment

**Construction**

Below, we summarise the findings of a report by the Building Research Establishment (BRE) on climate change and buildings:

- Higher winds will adversely affect anchoring of scaffolding and use of cranes;
- Higher temperatures and more sunlight would affect workers as sites are more dusty and chemicals more volatile;
- Higher temperatures causes cement materials to set more quickly, decreasing working time;
- Concrete is weaker if it dries too quickly;
- Plastic based materials are more susceptible to UV-B radiation;
- Building foundations face greater risk of attack from sulphates in soils due to greater mobility in warmer / wetter conditions;
- Site flooding may increase the need to pump out ground water before construction can continue. Wet soils may prevent use of heavy plant;
- More variable weather and more storms might result in the loss of work days. Past experience suggests that the building industry will adapt to prevailing weather conditions over the year by re-allocating work to more clement periods of weather (PSA: 126); and

- A higher ground temperature will render aqueous-based contaminants more soluble and mobile, though drier soils will have the opposite effect. In areas prone to flooding or heavy rain it would become more difficult to control contamination implying that containment measures may be more easily overcome or that the degree of containment spread or potential harmful effects is increased.

**Buildings**

- Chloride attack of buildings is likely to be reduced since its main source is de-icing agents, which will be used less at higher temperatures.

- Higher indoor temperatures may also cause greater out gassing of solvents and other pollutants from building materials and furnishings. Meanwhile, higher temperatures in the walls and cavities of buildings could lead to increased release of formaldehyde into internal building space.

- Timbers are at risk from the house longhorn beetle and termites which have established themselves in small colonies in the south of England (Berkshire and Hampshire) and when left for a period of time can cause serious damage. Their further spread is currently limited by temperature, so warming could result in their migration northwards.

- Poor quality concrete lacks durability due to corrosion, frost damage, sulphate attack and alkali-silica reaction. Future climate is likely to exacerbate any concrete durability problems. Concrete can also react with atmospheric $CO_2$ which will cause cracking, a process which will be accelerated by higher atmospheric concentrations of $CO_2$. High alumina cement (HAC) converts to a form of lower strength at higher temperatures, as has been discovered in the past when HAC beams were used in swimming pools.

- If driving rain becomes a greater problem, it may be necessary to redesign window detailing in England, perhaps adopting the Scottish approach, whereby windows are set on the inner rather than outer leaf. Greater protection of structures generally might be needed against rain penetration - eg using render, cladding, water repellents, etc.

- In high areas of high driving rain, cavity wall insulation can act as a bridge for moisture between the outer and the inner leaf of the structure, leading to penetration of rain through the structure. Where insulation becomes wetter, some of the energy savings from higher temperatures could be off set.

- Suspended timber floors in flooded areas may be prone to water being trapped between the concrete underslab and the floor timbers, which could lead to rot. Suspended concrete floors could also be affected, with frost damage and sulphate attack being more critical.

- Wind driven rain might get blown into the sub-floor space. And whilst an increased ventilation would also offset any increase in moisture ingress, higher relative humidities are likely to be encountered. The latter could result in greater condensation in buildings due to relatively higher humidities, roof voids being especially at risk. Higher winter temperature combined with higher vapour pressures could result in more severe problems.

- An increased ventilation rate could supply more oxygen in the case of a fire. Wind speeds and high ventilation rates were noted as one of the contributory factors in the 1997

Heathrow Airport fire. The need for protection would increase as the risk from external sources of fire increased - such as drought in nearby woodlands.

- Higher wind speeds are already included in structural building design, eg buildings are designed to withstand gusts up to 125 mph. An increase in the intensity of summer rainfall would test the ability of buildings to cope with excess surface water and may have implications for cellar flooding and erosion of buildings. Intrusion of sea water through coastal flooding has a very adverse effect upon buildings from which they may never fully recover.

- In the East Midlands the distribution of wind damage increases from the East coast inland towards the south west of the Region (Blackmore 1996). Domestic dwellings report the highest incidence of damage, being the most common type of building. However domestic dwellings also tend to perform less well in very windy conditions, because of age, poor workmanship or general deterioration. Much wind damage could be avoided if buildings with lightweight cladding and low pitch roofs are better designed and fixed, together with greater building inspection and maintenance.

- Radon gas will become more mobile, which is an important risk in areas of limestone (White Peak).

**Building Design: Adaptation to and Mitigation of climate change**

Climate change has not yet been factored in to building/construction design, apart from efforts to reduce energy consumption. Gusto Construction, based in Newark, has, for example, designed its buildings to reduce energy (hence carbon emissions) and to avoid the need for air conditioning systems.

- The high levels of **insulation** help to control the temperature in the summer and winter, so should make houses better adapted to higher external temperatures.

- Mechanical ventilation systems, where required, should be powered with solar panels and include heat recovery systems.

- **Grey-water recycling systems** are a useful means of storing excess stormwater for later droughts. Rain water is collected, stored in tanks and used for the toilets, washing, gardening, etc. The design of water recycling systems will be influenced by rainfall patterns – eg there will be a need to take account of how rainfall patterns will change over the next few decades due to climate change. The tank size will have to change if rainfall begins to happen more frequently in intensive bursts rather than drizzle over longer periods of time i.e. it will be necessary to collect more water over a shorter period of time. The storage tanks do not want to be over-sized, however, since the water has to flush through at a certain frequency.

- The issue for climate sensitive builders like Gusto is to know how will rainfall patterns change in specific areas in terms of when rain falls and how intensely. These, of course, are issues which climate change science cannot yet answer with any accuracy.

- Whilst separation of primary and secondary quality water is highly desirable with regards to new buildings, they are virtually non-existent in new housing. The only way this situation will change will be by pushing through tougher building regulations. Such regulations may be driven more by concerns over removing surface water than demand-side reduction.

**Adaptation of current building stock**

By 2020, 80% of the houses which are already present will still be standing. This raises the question of how much retrofitting could be done to existing buildings to adapt to climate change and make them more energy efficient and more generally climate-change sensitive. It is generally rather expensive to adapt existing buildings in this way costing perhaps £5000 to £7000. It will be difficult to persuade individuals to invest independently when there is reluctance to pay for loft insulation, which is much cheaper and has a very short pay back period. In Germany, grants are available for installing rainfall collection systems in the home. Many more new homes also have such systems. It may be that at the aggregate level, retro-fitting would be more economical than SevernTrent building a new reservoir and piping the water from Wales.

***Mitigation: Encouraging Change in Cultural Attitudes**:*

Sustainability as a Lifestyle Choice: Case study of Gusto Construction, Nottinghamshire

The issue of selling sustainability as a component of a healthy, desirable lifestyle was seen as critical by Gusto Construction and other participants in the Nottingham workshop. Selling a house on the basis of environmental concerns only appeals to around 7% of the market. So if the extra initial costs of the houses were packaged towards a "lifestyle" the financial costs are less of an issue – they would be absorbed.

"We are not designing to cope with climate change – we are selling a lifestyle".

**Examples of Environmental Buildings in the Region**

- Inland Revenue building in Nottingham (2000 staff) is environmentally-designed.
- Jubilee Building at University of Nottingham – environmental design and built on a very low budget, though it still managed to incorporate many good environmental design features.
- Sherwood Energy Village - this combines housing and energy generation (from wood chip fired power stations). People have local shares in the village.
- Hockerton Housing Project, Nottinghamshire
- Eco-House, Leicester - an ordinary house fitted with inexpensive energy saving devices.

### 5.3.9 Manufacturing / Services and Retail

Three important messages that came through from the involvement of the Greater Nottingham Business Alliance at the Nottingham workshop were:

- Businesses will need greater certainty in the projections of climate change before they take significantly forward the issue of responding to climate change impacts. They will find if very difficult to respond on the basis of scenarios which indicate significant differences in the rate of change in climate variables;
- Businesses will be very different by the 2020s and 2050s. Eg the current percentage of manufacturing industry (at about 24% for Greater Nottingham) will probably decline, perhaps by a half by 2020. Hence, assessing the impacts of climate change upon the current business profile is not necessarily a reliable indication of future vulnerabilities; and
- Companies would be much more prepared to respond to climate change impacts if there were a mechanism by which some of the money paid via the Climate Change Levy could be returned to companies as assistance to help adapt to the impacts of climate change.

**General Findings on Manufacturing and Services and Climate Change of Relevance to the East Midlands**

- Some production processes are sensitive to extreme temperatures (over 25 or 30$^{o}$C) and may require adjustment.
- Some processes are sensitive to a change in the quantity and quality of water supplies (eg from rivers, boreholes).
- Wastewater treatment facilities are sensitive to an increase in intensive rainfall, especially at sites where all water on site is collected and treated.
- Some coastal sites are sensitive to a rise in the sea-level.
- High summer temperatures can produce difficult working conditions for employees (over-heating, etc.). This is especially so in older factories and offices and in 'sunset' industries which cannot afford refurbishment.
- The supply and price of inputs from the UK or overseas may change as a consequence of climate change.
- Markets may change in response to climate change, eg textiles, building design, health and personal hygiene products, pharmaceuticals, etc.
- Air conditioning / cooling systems may be required in more factories, offices, and retail facilities increasing operating costs.
- Food processing companies may need to spend more on cooling and refrigeration systems. Perhaps more important will be change in the sourcing of ingredients. This could change supply-chains and transport logistics.
- Greater possibility of food poisoning arising for food processing and preparation industry. On the plus side, a wider range of fresh produce may potentially be available.
- Service and financial sectors seem to be generally less sensitive to climate change impacts than manufacturing. However, employees in poor quality, badly ventilated buildings in the service sector may be particularly affected.

- There is a reduction in retail spending in very hot weather as people prefer to spend time in other outdoors activities (Palutikoff et al., 1997).

**Findings Specifically Related to the East Midlands**

***Risks From Flooding of Manufacturing / Distribution Centres***

Some companies in the East Midlands are located on or close to flood plains and are vulnerable to future climate-change induced flooding. The 1998 flooding adversely affected several companies in the East Midlands including **Pedigree Pet Foods** in Melton Mowbray, Leicestershire, and **Church's Shoes** in Northampton. In the case of Pedigree, it took about one year for the company to fully recover. The flooding very nearly – but did not quite – bring production to a stop, which would have been very expensive for the company (£1 million a day). The ground floor of Church's Shoes factory in the St. James' area of Northampton was badly affected with machinery and raw materials being destroyed. Nearly the entire workforce voluntarily came into the factory over the Easter weekend to clear up the aftermath of the floods. Other local shoe companies helped by lending machinery and supplies of raw materials. The company also assisted its workforce, many of whose homes were directly affected by the flooding, eg by allowing flexible working arrangements and assistance in making insurance claims. The Environment Agency has undertaken re-assessments of flood risk in these cases, as part of local flood alleviation schemes. A new retaining wall has been constructed in Melton Mowbray, whilst a major flood protection scheme is proposed for the St. James area of Northampton, which is designed to protect against a 1:200 year flood event.

The memory and impacts of flooding remain high in the perceptions of the workforce and management: only when companies have experienced flooding do they perhaps fully appreciate the impacts. Many companies not affected by the April 1998 floods but situated near to flood plains have assessed the risks from flooding given the existing defences and have prepared mitigation plans. Examples here include **Long Clawson Dairy**, Melton Mowbray and **Acordis** in Derby.

***Risks Arising from a Change in Water Resources***

Companies which abstract water from aquifers are vulnerable to reduced availability of groundwater. **Mansfield Brewery**, for example, has two boreholes to abstract water from the Sherwood aquifer. The company has noticed a decrease in the level of the groundwater and have consequently used top-up tap water. The company does not consider that there is a decline in the quality of the product when tap water is used, but prefers bore-hole water as it is cheaper. Some work for SevernTrent Water suggests an over-all greater recharge for the Sherwood aquifer arising from climate change. However, the specific area around Mansfield, north Nottingham and Worksop shows a decrease in recharge in that same study, and this is where industrial abstraction is concentrated. Other issues for the brewing industry are how climate change might affect the sourcing of brewing ingredients such as barley and wheat malts and hops. Other companies use water for cooling, but have developed closed loop systems on site, so that they are less vulnerable to a change in supply. An example is **Glynwedd** in Derby, which undertakes sheet metal casting and some coating.

If - as was mentioned in the South East scoping study (Wade et al., 1999) – the brewing industry in the South East might relocate due to shortage of water for brewing, then the East

Midlands would be an attractive alternative location, given its close physical proximity to the South East market, good communication links and high quality water. Such relocation out of the South East of brewing, and other businesses (such as paper mills) and perhaps even new housing, could increase the demand for water in parts of the East Midlands. A scenario-planning approach could be used by the water companies, Environment Agency and East Midlands Development Agency in evaluating such relocation prospects and their implications for water resources.

***Risks Arising from Impacts upon Production Processes***

Manufacturing in the East Midlands is not highly susceptible to the direct effects of a change in temperature and rainfall - the exception being impacts on buildings discussed above. The relative lack of susceptibility reflects the predominance of small and medium-sized manufacturing facilities in the East Midlands. Where larger production sites occur, eg **Toyota** and **Rolls Royce** in Derby, or **Boots** in Nottingham, a high level of protection from intense-rainfall induced flooding is provided for. Eg the drainage system at Toyota is designed to cope with a 1:500 year rainfall event! Engineering is also more prevalent in the East Midlands than chemicals and other water intensive industries such as paper making, and the former appears to be less susceptible to the direct impacts of climate change than chemical facilities. Where water is used for cooling, higher ambient temperatures can reduce the efficiency of cooling, so requiring more water or installation of cooling systems, an issue mentioned by **Acordis** in Derby. Most food processing companies such as **Thorntons** are not directly susceptible to climate change because production processes, storage and distribution are temperature controlled already. However, the additional air conditioning and refrigeration required will mean higher energy bills. Equally important will be the change in sourcing of food ingredients on a global scale. **Boots** did not see any pressing issues arising from climate change impacts upon manufacturing. The company is already working hard to reduce waste water production and energy consumption through improved process efficiency. It is not working at the limits of its waste water capacity. Production could conceivably also move between manufacturing sites within the UK if water availability or high temperatures became a problem in the future. SMEs are inherently less able to relocate if climate variables were to unexpectedly affect operations.

***Change in Working /Retail Conditions***

A potentially important issue in the East Midlands is the impact of higher summer temperatures upon working conditions in offices and factories. The problem of over-heating has already been experienced at a number of companies throughout the early- and mid-1990s. At one firm, workers were encouraged to start work earlier or later on in the day, to avoid the hottest period. Also, workers were sometimes allowed to leave work early. The costs of installing air conditioning / mechanical ventilation are very high and actually impractical for open-plan factories. Climate change will exacerbate the problem of over-heating at work. Companies, and the Health and Safety Executive, need to start undertaking assessments and devising a response now. In the retail sector, great onus is placed on producing a pleasant environment for shopping and recreation, which normally means installing air conditioning. With climate change, the energy requirements for air conditioning in shops could increase in the future. There is a balance to be struck between creating a suitable internal environment for customers and reducing energy consumption. The issue will be important for Boots, 80% of whose business is now retail.

***Impacts of Climate Change Upon Markets***

Climate change could influence the demand for goods such as personal care/beauty products, products and services related to leisure, recreation and tourism, fashion, horticulture and gardening. Products such as shampoos may need to be redesigned to use less water if shortages become more common. Demand for suncare products could also increase. Responding to climate change impacts could produce new opportunities for building design, flood protection and drainage systems, and agriculture (plant breeding, biotechnology and agricultural engineering). Responding to climate change mitigation could also generate new markets in energy technologies. The region's universities, and companies such as BG in Loughborough, are undertaking RandD into possible alternative energy technologies such as hydrogen fuel cells. There are also abundant opportunities for many companies to work on production, distribution, retail and disposal systems which use less carbon than at present. In many instances, these changed markets will be global rather than local in scale. Hence, what climate change impacts occur in markets where products and services are sold internationally needs to be explored in further research or individually by companies in devising future strategy.

***The Climate Change Levy (CCL)***

Perhaps the most pressing issue that companies perceive from climate change is the introduction next year of the Climate Change Levy (CCL). This study has not concentrated on the CCL and mitigation-side issues, but a few relevant comments will be made below.

The CCL is influencing thinking in a number of companies about investment in new energy supply systems such as Combined Heat and Power (CHP), which is exempt from the CCL. Opportunities may exist for use of the heat generated in district heating, though there are planning and market barriers to operationalisation of such schemes. In principle retail and service companies should stand to benefit from the CCL because they are less energy intensive with relatively large workforces, for whom National Insurance Contributions are reduced. Much depends in practice, however, on how many of the staff are employed part- as opposed to full-time. At Boots, for example, 25% of the staff are part-time, and do not qualify for reduction in the NIC. With 2000 shops, Boots is a large, but not intensive, user of energy. Boots has a CHP plant in Nottingham, which sells electricity to the grid when there is surplus to requirements, and will benefit from no CCL charge upon this energy source. Boots are working with its distributors to test out new fuels (calor gas, low sulphur, etc) to reduce carbon emissions. The company has also been ‘back loading’ for many years – that is trying to ensure that its lorries are full up on return. It even co-operates with competitors to optimise freight use – eg they share in delivering goods to remote sites.

Water companies will have to pay the CCL. The additional costs to water companies of the CCL will be considerable, running into millions of pounds. This is providing a strong incentive for water companies to explore the availability of renewable energy which is exempt from payment of the CCL. With their large landholdings, companies such as SevernTrent could develop extensive biomass projects, an approach which is already being adopted by Yorkshire Water. Sensitively designed, biomass projects can enhance biodiversity and can also be used for recycling treated sewage sludge, so reducing energy costs of incineration. The overall effects of biomass upon reducing carbon emissions could, therefore, be considerable.

### 5.3.10 Insurance

**General Findings on Insurance and Climate Change of Relevance to the East Midlands**

- There are four types of extreme weather which give rise to domestic insurance claims: hot dry summers, leading to subsidence on clay soils, wind damage (especially if accompanied by heavy rain), freezing weather and river flooding. Apart from major claims for the storms of 1987 and 1990, there has been no evidence of any long term trend in the cost of such claims in the UK. However, there is evidence from one company (General Accident) of a steady increase in all weather-related costs from 1969 to 1990, over which time those costs have quadrupled (Witt 1998).

- The large areas of clayey soils in the East Midlands are potentially vulnerable to subsidence during drought years, though the problem is regarded as less serious than it is in the South East.

- Whilst the freezing period in 1996 pushed up claims from a background of around £250 million to £500 million, this is small in comparison to the £1900 million (1996 prices) claimed for the 1990 storms (Palutikof 1999). Claims from freezing pipes would be expected to decline due to warmer winters.

- The insurance sector is somewhat unusual in its ability to adjust charges rapidly in response to perceived changes in the risk profile underwritten. Without major climate change-induced events, the industry is reluctant to increase premiums or demand greater differentiation in underwriting of risks (eg avoidance of underwriting in high risk flood areas) due to intense competition, the relatively cheap price of re-insurance and the lack of detailed knowledge on the risks of specific properties. Nevertheless, there is no guarantee that these circumstances will remain constant. Indeed, the UK market is highly unusual in that the private sector will underwrite flood risk at all.

### 5.3.11 Public Health

**Health risks from climate change**

- Heat stress is one of the potential negative impacts of an increase in UK summer temperatures. Previous hot spells have shown a definite increase in mortality in the UK. During the 1976 and 1995 summers the daily death rate was seen to increase 8-9 % in England and Wales (WHO 1999). In addition it is thought that the problems of urban air pollution will be exacerbated by climate change by enhancing the production of photochemical pollutants, and possibly enhancing the biological impacts of certain pollutants (CCIRG 1996).

- A possibility of malaria outbreaks in the UK by 2050: it has been found that efficient vectors of malaria could carry a strain from Eastern Europe or the Mediterranean - areas which under the WHO's analysis are very likely to see an increase in the spread of malaria. Recent modelling work shows that the UK would become a suitable home for malarial mosquitoes in the climate anticipated by the 2050s (WHO 1999).

- There has been an increase in the incidence of Lyme disease from ticks as a result of milder winters. Whilst partly a result of people spending more recreation time outdoors, a positive correlation has also been found between the number of cases of lyme disease and summer temperatures in central England (Subak 1999). Tick populations are believed to be limited by a very dry period, but can be encouraged by milder winters, so in future there may be an increase in incidence.

- If future winters were to be wetter and windier then there would be a likely increase in the risks of condensation in the home (CCIRG 1996). This could increase the incidence of bronchial illness caused by dampness in the home, which already affects a substantial number of people during the winter in the UK.
- Previous episodes of flooding have been associated with an increased risk to human health arising from the spreading of infectious agents from sewage or even food waste onto land (Clark 2000).
- Incidence of food poisoning increases in hotter weather. Several thousand cases more per year would be expected with an increase in temperature of 2$^{o}$C.
- There are health issues arising from the leaching of wastes from older landfill sites due to a rising water table and from intense rainfall. Also, there are potentially critical issues arising from more flooding of old mine workings generating flows of contaminated water into waterways.

**Health benefits from climate change**

- Warmer winters would decrease the death toll from cold temperatures in poorly insulated homes. This benefit is expected to outweigh the increase in deaths from heat stress up to the 2050s.

### 5.3.12 Energy

Taking an overall look at climate change and energy demand it is thought that there could be energy savings for households and businesses arising from warmer winters, though this could be off-set to some extent by increased air conditioning/artificial ventilation in offices and factories. Increased storminess will increase the risk of disruption to the distribution network and could require re-design or new investment being planned.

There are a number of power station along the Trent Valley providing energy for use inside and beyond the Region. In order to explore the potential impacts of climate change of power stations and related infrastructure a meeting was held with Powergen, an energy generation company that operates fossil fuel power stations in the Region. They are also a renewable energy developer. Following their research, they felt that is was unlikely that there would be any major surprise impacts of climate change on their power stations and supply network eg flooding, storm damage and higher cooling water (river) temperatures leading to reduce generation efficiency. They are familiar with these types of events and they are taken into consideration in the design and operation of the stations. Adjustments are and would be made in response to changes in impacts through the existing investment and maintenance programmes. They have identified some minor impacts that climate change could contribute to but that were already being addressed through their programmes eg ground shrinkage leading to cable rupture. They felt that there could be a shift in demand from winter to summer but the system could readily respond to this. They are assessing the impact of the climate change levy (energy tax on the business use of energy) on customer demand. This discussion should be considered agrainst the background of major changes in the power generation sector such as new electricity trading arrangements (leading to more competition), a shift to less carbon intensive generation methods (gas and renewables), increasing regulation on some power station emissions (but not $CO_2$) and changes in consumer demand.

### 5.3.13 Coastal Zone

"To rebuild the beaches along the long and vulnerable coastline of the East Coast is a massive programme which will never be completed" (Environment Agency)

The most significant case of coastal inundation in Lincolnshire occurred in the storm surge of 1953, affecting the East coast of England. A deep depression entered the North Sea from Shetland, tracking towards north west Germany bringing strong north west gales and coinciding with high tide at Harwich and Immingham (Jensen 1953). Although 300 people lost their lives in Eastern England (41 in Lincolnshire) and large areas of land were flooded when defences were breached, the Region suffered less than the Netherlands (where nearly 1800 people were drowned). Eastern England was not so fully exposed to the effects of the gales producing the highest tides. Nevertheless tides were 8ft higher than predicted at Kings Lynn (*ibid*.). Further surges occurred in 1976, 1978 and 1983, these storms gradually destroying large parts of the peir at Skegness.

One third of Lincolnshire is below mean sea level and there are 130 km of coastal sea defences. Resorts and other local towns such as Boston, Mablethorpe and Skegness are protected by these defences. The coastal defences from the Humber mouth to Skegness rely upon natural sand dune systems and beaches with sand moving from north to south along the coast (East Midlands Regional Biodiversity Forum, 1999). Between Mablethorpe and Skegness the hard defences have been supplemented by recharging the beaches with marine dredged sand taken from areas further offshore (ibid.). Around the Wash the defences rely upon earth banks and large expanses of saltmarsh.

Sea levels relative to land levels rose by an average of 1.1 mm between 1960-1995 at Immingham. By 2050 the cumulative rise will be 370mm. The Lincshore project, which covers 19 km between Mablethorpe and Skegness, is a coastal defence project currently underway along some of most vulnerable coastline in Britain; the affected area includes 35,000 residents in 15,000 homes and 18,000 residential caravans, as well as 20,000 hectares of land (UKCCIRG 1996). Marine sand is being dredged off the Lincolnshire coast to supply sand for the Lincshore coastal defence project. Sand is pumped onto beaches, where it will be washed back into the sea, and eventually re-dredged to be used again (Environment Agency 1996). This is a 'soft' approach to coastal defence, which can restore current swept sand systems which supplement the natural dune defences. The beach nourishment approach was preferred over attempting to maintain a concrete-based sea-wall defence or use of rock groynes, offshore breakwaters or artificial headlands. The other approaches result in continuing beach erosion. The action of the sea on concrete slabs has been to erode the clay underlying the sand into which the concrete is set. This then led to the toe of the concrete blocks being exposed and the collapse of the defences. Although design improvements can improve the resistance to overtopping, and to some extent reduce the rate of beach lowering, the beaches would continue to fall and new walls would eventually be needed which are bigger and stronger (Lincshore'97).

The shoreline of the Wash is mainly stable with some areas of retreat, although the sandy coast near the mouth of the Humber and south of Skegness is still extending seawards (East Midlands Regional Biodiversity Forum, 1999). Hence, the problem of 'coastal squeeze' is less pronounced in Lincolnshire than it is in East Anglia. Managed retreat or "managed realignment" of land use as it has come to be known has been pioneered in the UK by local authorities situation along the Eastern England coastline, including Norfolk, Essex and Lincolnshire. One of the first examples of managed retreat in the UK is taking place at Freeston near to Boston on the Wash, where land was reclaimed for agriculture in the 1970s. The privately owned primary sea wall is being abandoned, whilst the secondary sea wall is being adopted by the Environment Agency as the new primary defence. 80 hectares of saltmarsh will be created along with 14 ha of brackish marsh and a visitor centre and hides will be constructed. It is anticipated that the project will promote tourism in Boston and birds such as waders, widgeon, twite, turns and Brent Geese should be attracted to the site. It must be noted, however, that managed retreat has been evaluated on several schemes on the Lincolnshire coast in the past and in every case rejected on economic grounds (Steve Vernon, pers.com., June 2000).

Areas of tourist resorts such as Skegness have been developed in the past in the sand dune and beach areas, creating a need for hard defences against a 1:200 year storm event. Such areas would now not be developed as they could, if undeveloped, serve an important function as natural flood protection zones. The challenge now is to provide sufficient protection whilst not destroying the visual or economic attractiveness of the resort - as noted earlier, tourism is vital to the local economy in coastal Lincolnshire. Some companies have been reluctant to locate attractions in such areas because of flood risks and the difficulty of obtaining insurance cover. One insurance company has even invested in a client's flood defence system so that its level of risk is reduced. It should be noted, however, that major investment has been taking place in Skegness and other resorts such as Ingoldmells (eg Butlins). Further detailed and localised research on the potential impacts of climate change is likely to be necessary along parts of the Lincolnshire coastline.

## 5.4 References


Berkhout, F. et al. (1999), *Non-Climate Futures*, SPRU, University of Sussex

Blackmore (1997) Gales and structural damage in the UK, Journal of Meteorology No.? , 223-235

BRE (1998), *Impact of Climate Change on Building,* Garvin, S., Phillipson, M., Sanders, C., Hayles, C. and Dow, G., Building Research Establishment, Scottish Laboratory.

Bridgeman, J. and Gregory, J. (1999), 'The Potential Impact of Climate Change Upon Sewerage', STW Ms.

Brignall A P, Rounsvell M D A (1994) *The effects of future climate change on crop potential and soil tillage opportunities in England and Wales*, Soil Survey and Land Research Centre, Cranfield University, University of Oxford pp.94

Buckland et al (1997) A comparison of plant responses to the extreme drought of 1995 in northern England, Journal of Ecology **85** 875-882

Burroughs, WJ (1997) *Does the weather really Matter? The social implications of climate change,* Cambridge University Press, Cambridge pp240

Bye P, Horner M (1998) East 1998 Floods: Report by the Independent Review Team to the Board of the Environment Agency, submitted 30 September 1998.

Clark C (2000) "Storm flood and soil erosion: The consequences of the storm of 13 May 1998 at Hadspen, Somerset", Weather **55(1)** 17-25

Crick H Q P, Sparks T H (1999) "Climate change related to egg-laying trends", Nature **399,** 423-424

Crosson P, Rosenberg N J (1993) "An overview of the MINK study Paper 2" Climatic Change **24** 159-173

Danby, I., Goodyear, J. and Branscombe, J. (2000), *Vanishing Wetlands: Water Abstraction and other Threats to Wetlands in the East Midlands*, Nottinghamshire Wildlife Trust, 16pp.

Duckworth, B. (1999), "Why Climate Change is so Important to the Water Industry", Paper presented to the Climate Change Conference, ICC, Birmingham, 26th May 1999.

East Midlands Regional Biodiversity Forum (1999), *Sustainability and Biodiversity: Priorities for Action in the East Midlands*, c/o English Nature, Grantham, Lincs.

Edwards J B (1999) "The temporal distribution of road accidents in adverse weather", Meteorological Applications **6** 59-68

Environment Agency (1996) *The Lincshore Project*, Public Relations Dept, Environment Agency, Peterborough

Environment Agency (1998), *Progress in Water Supply Planning: The Environment Agency's Review of Water Company Water Resources Plans*, Bristol.

Environment Agency (1999) *Viewpoints in the East Midlands Environment*, Environment Agency, Solihull pp.93

Environment Agency (1999a), *Strategic Review of Development and Flood Risk: Nene Catchment Northampton and Upstream*, Bristol.

Giles A R, Perry A H (1998) " The use of a temporal analogue to investigate the possible impact of the projected global warming on the UK tourism industry", Tourism Management, **19(1)**, 75-80

Harrison S, Foster I (1999) "The August 1996 flood event at Ashow, Warwickshire", Weather, **54(5)**, 143-147

Hawley, D (2000), Environment Agency, personal communication, April 2000.

Hodkinson, D J, and Thompson, K. (1997), "Plant dispersal: the role of man", Journal of Applied Ecology, **34**, 1484-1496.

Holt C P (2000) "Characteristics of the Northampton rainstorm of 9 April 1998", Weather, **55(3)**, 78-84

Hough M N, Hollis D (1998) "Rare snowmelt estimation in the United Kingdom", Meteorolocal Applications, **5(2)**, 127-138

Hulme M, et al. (1999) "Relative impacts of human-induced climate change and natural climate variability", Nature **397** 688-691

Jaggard K W , Dewar A M, Pidgeon J D (1998) "The relative effects of drought stree and virus yellows on the yield of sugarbeet in the UK, 1980-95", Journal of Agricultural Science, **130**, 337-343

Jensen HAP (1953) "Tidal Inundation Past and Present", Part 1, Weather, **8(3)**, 85-89

Johns M (1998) "The Impact of Grazing and Upland Management on Erosion and Runoff", Technical Report **P123**, Environment Agency, Bristol pp.43

Kay R (1991) "Coping without concrete" Town and Country Planning 11-13

Kerr, A., et al. (1999), *Climate Change: A Strategy for Scotland*, Scottish Executive, Edinburgh.

Kilsby et al. (1998) "Predicting Rainfall statistics in Enlangd and Wales using atmospheric circulation variables", International Journal of Climatology **18** 523-539

Kitson, T. (1998), "The Implications of Climate Change on Water Resources", Paper presented to the IBC Conference, London, 25th November 1998.

Kitson, T. (1999), "The Truth About Water Resources: A Traverse from the Wet West to the Dry East", Paper presented to the Climate Change Conference, ICC, Birmingham, 26th May 1999.

Leeds Harrison P B, Rounsvell M D A (1993) "Impact of Dry Years on crop water requirements in Eastern England", Journal of the Institute of Water Engineers **4**

Lincshore'97: An Environmental Statement, NRA, Anglian Region, 1997.

Marsh T J, Sanderson FJ (1997) "A review of hydrological conditions throughout the period of the LOIS monitoring programme - considered within the context of the recent UK climate variability", The Science of the Total Environment **194/195** 56-69

McKenzie-Hedger, M., Gawith, M., Brown, I., Connell, R. and Downing, T. (Eds.), (2000), *Climate Change: Assessing the Impacts - Identifying responses. The first three years of the UK Climate Impacts Programme*, UKCIP Technical Report, UKCIP and DETR, Oxford.

MAFF (2000), *England Rural Development Plan 2000-2006: East Midlands Region*, January, 2000.

Menzel A, Fabian P (1999) "Growing season extended in Europe", Nature, **397**, 659

National Rivers Authority (1992) *Welland and Glen River System Flood Defences along the Welland and Glen*, National Rivers Authority (Anglian Region), Peterborough, pp4.

National Rivers Authority (1996) *Lower Witham Catchment Management Plan*, National Rivers Authority (Anglian Region), Peterborough, pp45.

National Trust (1998) "Climate Change", *Paper presented by the Head of Nature Conservation and Environmental Practices Adviser on behalf of the Chief Agent*, Annex IV to Council Agenda

National Trust (1997) "Soil Protection Policy Statement" Draft 3, *unpublished document*, National Trust, pp11

Orson (1999) "A review of the impact of the hot, dry summer of 1995 on the main agricultural and horticultural enterprises in England and Wales", ADAS, Kidlington, Oxfordshire pp.172

Palutikof J P (1999) "Domestic property insurance claims" in *Indications of Climate Change in the UK*, DETR, 28-29

Palutikof, J, Subak, S and Agnew, M (eds.) (1997), *Economic Impacts of the Hot Summer and Unusually Warm Year of 1995*, UEA, Norwich.

Parmesan C et al. (1999) "Poleward shifts in geographical ranges of butterfly species associated with regional warming" Nature **399** 579-583

Parry et al. (1996) "Integrating Global and Regional Analyses of the Effects of climate change: A case Study of Land use in England and Wales", Climatic Change **32**, 185-198

Parry M (1990) "The potential impact on agriculture of the greenhouse effect", Land Use Policy **7(2)** 109-123

Rosenberg N J et al (1993) The MINK methodology background and baseline Paper 1, Climatic Change **24** p. 7-23

Rounsvell M D A and Brignall A P (1994) "The potential effects of climate change on autumn soil tillage opportunities in England and Wales" Soil and Tillage Research **32** 275-289

RSPB (2000), Meeting with RSPB and Environment Agency officials, February 2000, Solihull.

Shackley, S. et al. (1998), *Changing by Degrees: The Impacts of Climate Change in the North West of England*, Sustainability Northwest, Manchester, 63pp.

Sparks T H and Loxton R G (1999) "Arrival date of the Swallow" in *Indications of Climate Change in the UK*, DETR, 62-63

Spellman, G (1999) "Wet Aprils in Northampton" Journal of Meteorology, **24**, 47-51

Stern E, Zehavi Y (1989) "Road safety and hotweather: a study in applied transport geography", Transactions of the Institute of British Geographers **15**, 102-111

STW (1999), *Notts Trias Model: Climate Change Scenarios*, conducted by Entec UK Limited for SevernTrent Water Ltd, April 1999

Subak S (1999) "Incidence of lyme disease in humans " in *Indicators of Climate Change in the UK*, DETR, 38-39

Taylor J (1997) "Perceptions of bracken" The *Heather Trust Annual Report* 33-37, The Heather Trust, Kippen, Stirlingshire, Scotland

Thornes J E (1997) “Transport” in *Economic Impacts of the Hot Summer and Unusually Warm Year of 1995*, University of East Anglia 129-138

Thomas C D, Lennon J J (1999) “Birds extend their ranges northwards”, Nature, **399**, 213

Thompson K, Masters G J, Grime J P, Brown V K, Hillier S H, Clarke I P, Askew, A P, Corker D, Kielty J P. (2000), "Predicting the response of limestone grassland to climate change", Aspects of Applied Biology **58**, (in press)

Thompson R (1999) “A time series analysis of the changing seasonality of precipitation in the British Isles and neighbouring areas”, Journal of Hydrology **224** 169-183

Tipping E et al (1998) “Climatic influences on the leaching of dissolved organic matter from upland UK moorland soils, investigated by a field manipulation experiment”, Environment International (publication date not known)

United Kingdom Climate Change Impacts Review Group (1996) *Review of the Potential Effects of Climate Change in the United Kingdom*, Second Report, HMSO, London pp247

Wade, S. et al. (1999), *Rising to the Challenge: The Impacts of Climate Change in the South East in the 21st Century*, WS Atkins, Epsom, 94pp.

Witt, D. (1998), 'Insurance', in *Ill Winds and Silver Linings: Views on Climate Change in the North West of England*, North West Regional Association, Wigan.

World Health Organisation [WHO] (1999) *Seminar on Climate Change and Health*, UNFCCC Conference, Bonn 2.11.99

# 6. East Midlands' Stakeholder Perceptions of Climate Change

*Main Authors: Dr Simon Shackley and Dorian Speakman, UMIST*

## 6.1 Results of the Postal Questionnaire and Analysis

A detailed postal questionnaire to assess perceptions of climate change in the East Midlands was sent to nearly 1000 stakeholders in the East Midlands, including industry and commerce, local government, agencies, public health officials, NGOs, and other East Midlands contacts who have previously expressed an interest in sustainable development. 194 responses have been received - a response rate of about 20%. This is a good response rate given the difficult and quite technical nature of the questionnaire. A copy of the questionnaire is presented in Appendix II.

### 6.1.1 How Important is Climate Change Relative to Other Key Issues?

One of the most striking findings is that the respondents consider climate change to be the **third most important issue out of ten** current issues for public debate and concern in the East Midlands, this is illustrated in Figure 13 below. The most important issue for the Region is, by a significant margin, transport, followed by economic restructuring. Climate change comes third, followed by local air pollution, with little to chose between new development (eg building), and loss of nature in fifth and sixth place. For this group of stakeholders, e-commerce, interest rates and GMOs were relatively less important for the East Midlands.

### 6.1.2 The Impacts of Particular Types of Climate Change

We asked respondents to assess the impacts of particular types of climate change: change in average temperatures, rainfall, extreme temperatures, and sea-level, along with an indication of their level of confidence in their own response. The climate changes indicated are consistent with the UKCIP ‘high’ scenario for 2050. The results are summarised in Figure 14 and the distribution of responses shown in Figures 15-20.

What can be seen here is that changes to sea-level and coastal flooding are regarded as the most serious impacts, followed by a decrease in summer rainfall. Increasing average temperatures and an increase in extreme temperatures are closely ranked, with a increase in winter rainfall seen as the least significant impact of climate change. Analysis of the respondents' levels of confidence (not shown here) concerning each impact revealed that there was less confidence about the impacts of a change in average temperatures, extreme temperatures and change in rainfall patterns. This is as would be expected given that the impacts of a rising sea-level and enhanced risk of flooding are easier to envisage than a change of, say, $2^{o}$C in average temperatures. Our existing knowledge is less well developed on how sensitive societal, economic and environmental systems are to a change in temperature, incremental or extreme.

### 6.1.3 The Impacts of One Climate Change Scenario Upon 20 Sectors

The respondents were asked to assess the impacts of a 'high' scenario of climate change by 2050 upon 20 different sectors ranging from flooding to lifestyles. The distribution of responses for each sector is shown in Figures 21-40. The overall assessment of the 'seriousness' of the scenario for each sector is shown in Figure 42.

Using a weighting system, all the positive and negative assessments of the impacts of climate change for each of the 20 sectors are included. The overwhelming perception is that climate change will have negative rather than positive impacts. Only **tourism** and **lifestyles and leisure** come out as overall positive, and then by a smaller extent than the big two negatives: **Lincolnshire coastline** and **lowland flooding**. Tourism is perceived as the sector with the most positive impact, whilst impacts upon **lifestyles and leisure** are regarded as being about as positive as impacts on **insurance** are negative. For all twenty climate impact domain areas, however, some respondents did identify positive impacts. The other main sectors where it was felt that impacts would be negative were: **regional water supply and demand, agriculture and horticulture, regional economy, public perceptions** and **biodiversity**.

Figures 22 and 29 show very clearly the extent to which there is a consensus on the negative impacts on the coastline and on lowland flooding. Meanwhile, Figures 30, 31 and 32 show the neutral to fairly negative assessment of impacts upon forestry, human health, and working conditions, with the third most common response being fairly positive. Figure 23 shows the neutral to fairly positive assessment of impacts on lifestyles and leisure, a pattern which is repeated in Figure 37 for tourism. The impacts on regional water supply, waste water management and urban areas are regarded as generally fairly negative, with neutral or very negative being the second most common response (Figures 24, 25 and 26). As for impacts on manufacturing, services and retail, there is reasonable consensus around the neutral response (Figures 33 and 34). When it comes to impacts on the regional economy as a whole, opinion is more divided, with a fair spread of responses between neutral, fairly negative, fairly positive and unsure, though neutral was the common response at 40%. An even more distributed set of responses were received for impacts on public perceptions (Figure 38), from fairly positive to fairly negative.

Overall, the most common responses were 'neutral' and 'fairly negative'. Relatively few respondents chose the 'unsure' category (from nearly 0 to 15% - typically about 10%) in this and other questions. Where responses are more distributed between response categories, the 'unsure' category tends to be higher, which is what would be expected. Some respondents commented on the difficulty of completing the questionnaire and many noted that the response was a subjective judgement, not informed by objective scientific assessment (which is the set of perceptions that we were aiming to evaluate). Several respondents declined to complete the questionnaire because they felt unable to provide a single response to the assessment of impacts across the sectors. For example, the impacts of climate change on the coastline could well be negative and positive for biodiversity, and how can that be expressed by one of the 6 categories provided? (Our intention was that in such situations the respondents would weigh-up the positive and negative impacts and decide on the net effect or choose the neutral category if such a comparison proved impossible.).

We also asked respondents to rank 10 impact domains in order of seriousness (Figure 41). Since this was a relative ranking exercise, it did not produce such a refined analysis as that shown above where a choice of six responses is available to the respondent. Nevertheless,

Figure 41 does confirm that flooding is the number 1 issue, followed by coastal zone, water supplies, agriculture and horticulture, biodiversity and heath. The least important effect was upon services and retail, followed by tourism, lifestyles and manufacturing.

These results are broadly consistent with the discussions in the 5 stakeholder workshops (see Appendix I) that were conducted, where some potential benefits were identified for not only tourism, but also agriculture and horticulture, services and retail and human health. Clearly, the workshop discussions were able to consider more explicitly **responses to climate change** beyond 'business as usual' when considering the impacts. For instance, benefits along the coastline were identified from climate change in terms of encouraging a move towards managed realignment of the coastline which could have benefits for biodiversity through habitat creation. The stakeholder discussion groups identified water supply and demand as potentially very negative - though the consensus was that too much uncertainty exists for any precise judgement to be made. The workshops also identified biodiversity as suffering some big adverse hits, with significant uncertainty attached to what 'gains' might off-set the losses. The results indicate where there is a need to communicate the key messages of the scoping study vis-à-vis particular groups of stakeholders. Several respondents identified impact domains additional to our twenty, namely: impact of higher temperature upon childrens' attention span, air quality (x3), navigation and waterways (x2), property prices in Lincolnshire (x2) and habitat maintenance.

### 6.1.4 Greenhouse Gas Emission Reductions

When we asked how a reduction of 20% in $CO_2$ emissions by 2010 (relative to 1990) could be achieved we found that less than a quarter preferred the Climate Change Levy, and only 15% favoured tradeable pollution permits (see Figure 43). On the other hand, nearly a third wanted to see more support for energy efficiency measures and about a quarter saw renewable energy as the way forward. In interpreting these results, it should be borne in mind that tradeable pollution permits, and possibly the climate change levy, are likely to be less known about than energy efficiency and renewables. Other options mentioned by respondents were: woodland carbon sinks, improved public transport and liquid petroleum gas (LPG) vehicles and lifestyle changes. It is interesting, however, that so much support was forthcoming for energy efficiency and renewables, suggesting that a strengthening of policy in these areas would be widely supported.

Nearly two thirds of the sample considered that the East Midlands should adopt the same target for emission reductions as the Government (see Figure 44). However, nearly a third wanted to see a higher target, and a smaller percentage a lower target. The arguments supporting such judgements ranged from suggesting that a higher target would provide the leeway to enable a realistic reduction of 20%, to the disproportionate effects of carbon emission reductions on the East Midlands compared to the South East (given its more energy intensive industrial composition) and hence the need for a lower target.

Finally, we asked the respondents what emission reductions might be required by 2050. The overall answer was 45% reduction relative to 1990 levels. This is an encouraging result since it suggest that our sample is well informed about the need for emission reductions to continue into this century beyond the 'Kyoto' requirement of 12.5% or the domestic target of 20%.

### 6.1.5 Differences between Business and Non-Business Responses

Approximately 50% of the responses were from business, the other 50% being from public sector, voluntary sector and NGOs. We analysed the responses to identify where there was a significant difference in the responses of the business and non-business respondents. We found that there was no significant difference in the perception of the impacts of climate change amongst the two groups (see Figures 45-48). There was a slight (but not significant) difference in the perceived impacts upon biodiversity and services/retail, with the non-business sample rating the former more highly and the latter less highly than the business sample. This indicates a surprisingly high degree of consensus amongst the respondents on the impacts of climate change.

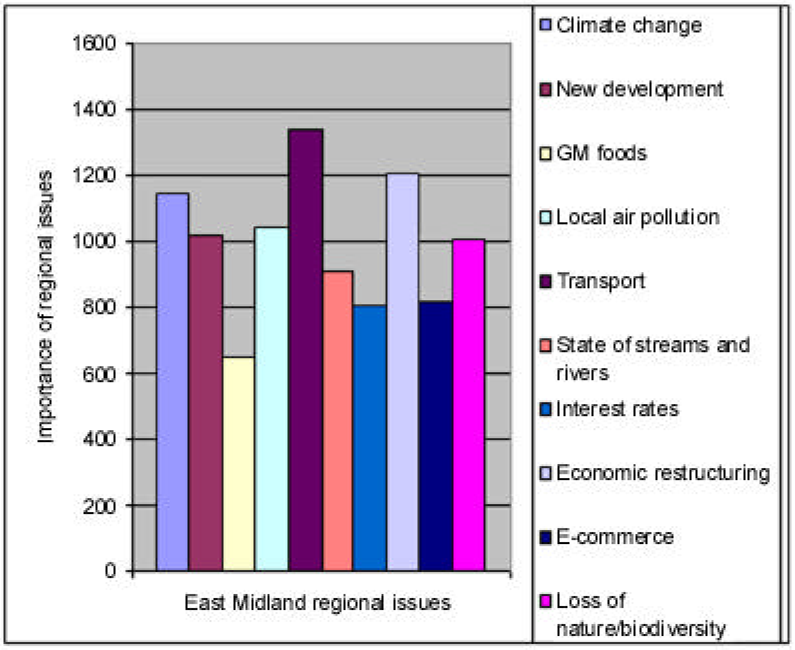
When it comes to measures to reduce emissions, businesses were in general less keen on renewable energy and more keen on 'other measures' than the non-business sample (see Figures 49 and 50) but once again there is a surprisingly high degree of consensus over the role of the Climate Change Levy and tradeable pollution permits. A more surprising result is illustrated in Figures 51 and 52, where it can be seen that business respondents generally support a higher target for the East Midlands in terms of emission reductions than the non-business sample (which was more likely to support a lower target for the Region than the government's national target of minus 20%). The reasons for this counter-intuitive result are not known, but deserve further investigation. Finally, the ranking of the 10 key issues for the East Midlands shows that the business and non-business samples once again show a high degree of consensus, with no differences in the ranking of the ten issues (Figures 53 and 54).

### 6.1.6 Summary

In summary, our respondents appeared to be informed about climate change and felt reasonably confident about answering the questions. Climate change was identified as the third most important issue for the Region out of a set of 10 contemporary social, economic and environmental issues. Their perceptions of the impacts of climate change were largely negative, especially with respect to coastal and lowland flooding and insurance, though across the board respondents did identify some positive impacts. Tourism, lifestyles and leisure were regarded as benefiting, from climate change though not as much as flooding and the coast would be adversely effected. The predominantly negative perceptions of climate change impacts may have been influenced by an implicit “business as usual” assumption in how we might respond to the impacts. The respondents wished to see more emphasis on energy efficiency and renewable energy generation in meeting the greenhouse gas emission reduction targets, in addition to the Climate Change Levy and emissions trading. Most of the sample regarded the UK's domestic $CO_2$ reduction target of 20% as appropriate for the East Midlands, though nearly a third thought that the Region should have a tougher target. The need for a 45% reduction in $CO_2$ emissions by 2050 was identified. Finally, analysis of the business and non-business respondents illustrated a very high degree of consensus in perceptions of the impacts and responses to climate change in the East Midlands.

## Stakeholder Perceptions of Climate Change

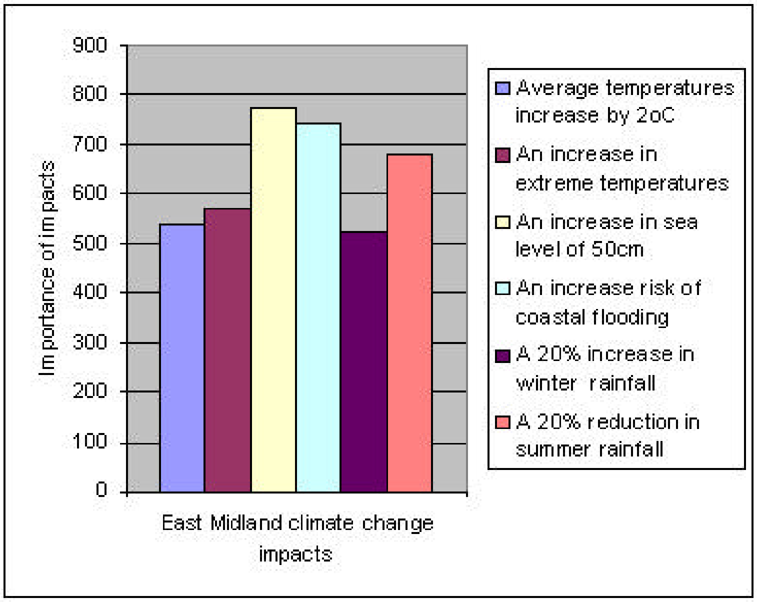
**Figure 13** Importance of East Midlands Regional Issues*




***Respondents were asked to rank the issues on a scale from 1 to 10, with 1 being the least important issues and 10 the most important. To determine importance, we have aggregated the rankings for each impact**

## The Impacts of Climate Change

**Figure 14** Climate change impacts ranked in order of seriousness for the region*




*Respondents were asked to rank the impacts on a scale from 1 to 10, with 1 being the least important impact and 10 the most important. To determine importance, we have aggregated the rankings for each impact

**Figure 15** Assessment of the effect of an increase in temperature of 2$^{o}$C

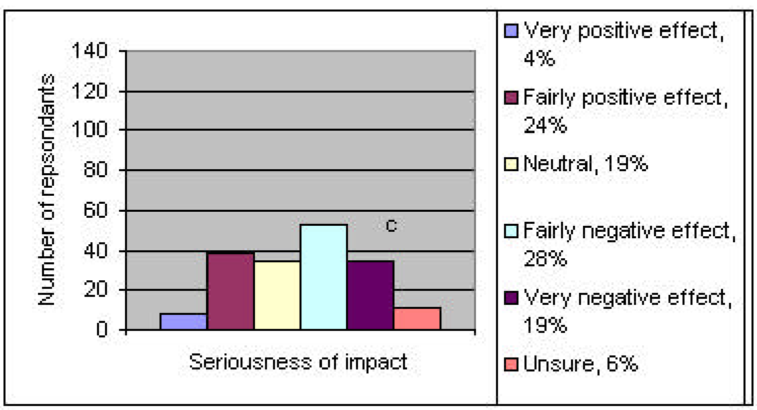


**Figure 16** Assessment of the effect of an increase in sea level of 50cm

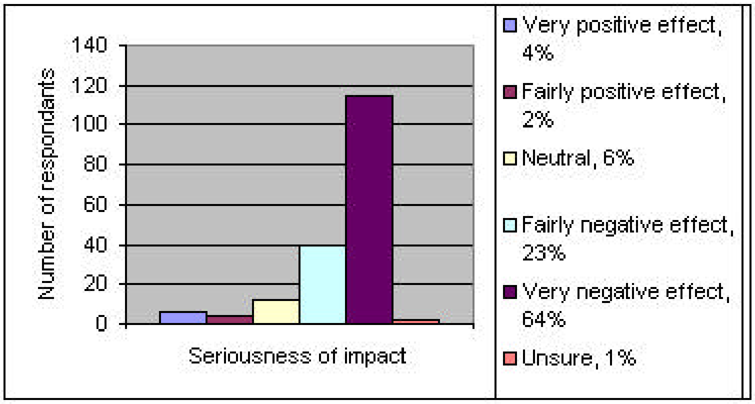



**Figure 17** Assessment of the effect of an increase in extreme temperature

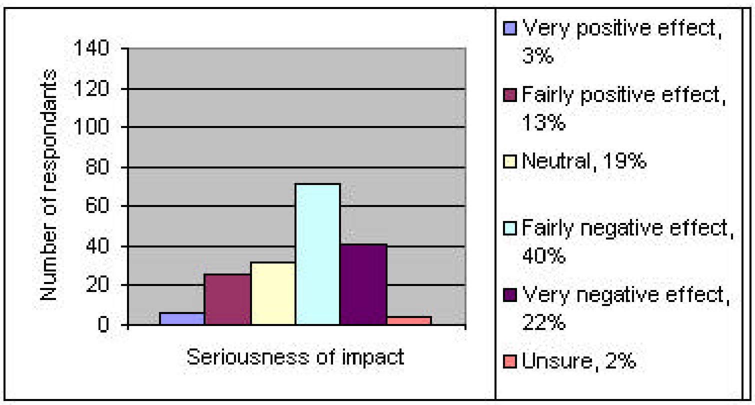



**Figure 18** Assessment of the effect of an increased risk of coastal flooding

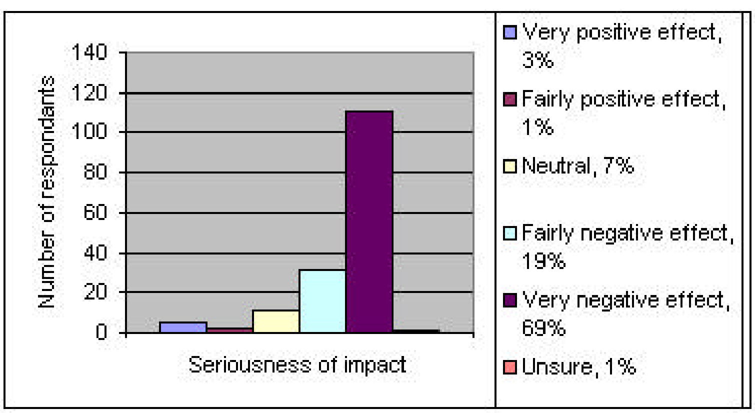


**Figure 19** Assessment of a 20% increase in winter rainfall

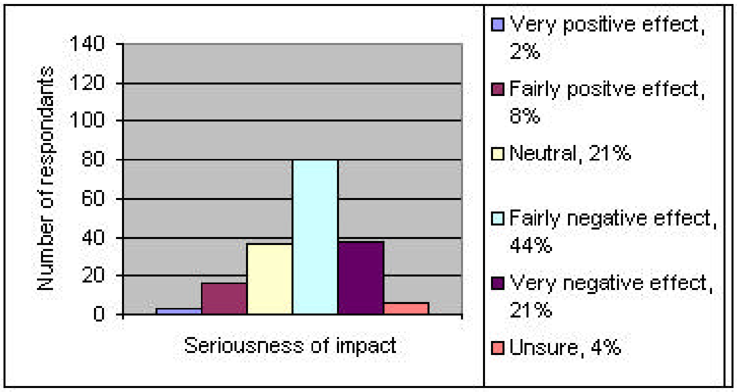
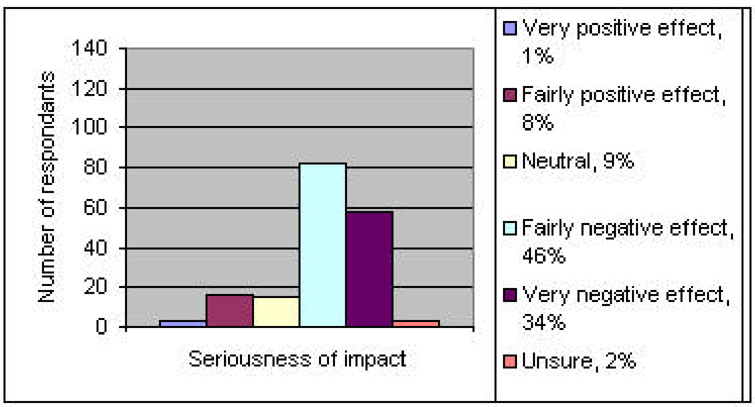



**Figure 20** Assessment of a 20% decrease in summer rainfall



**East Midlands' Stakeholder Perceptions of Climate Change**

**Figure 21** Impact of scenario on nature and biodiversity

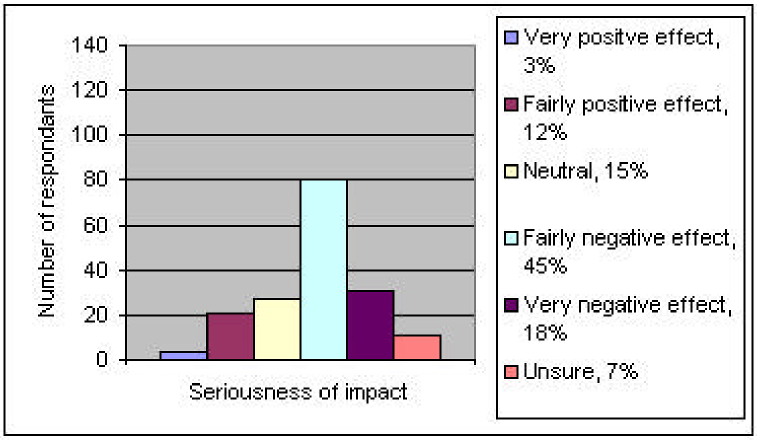



**Figure 22** Impact of scenario on Lincolnshire coastline

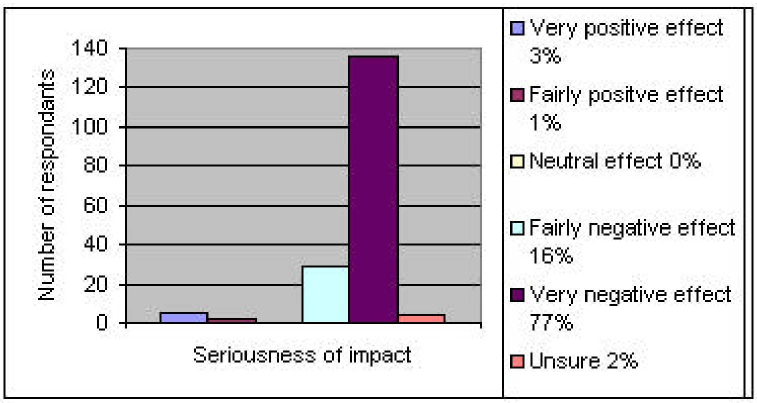



**Figure 23** Impact of scenario on lifestyles and leisure

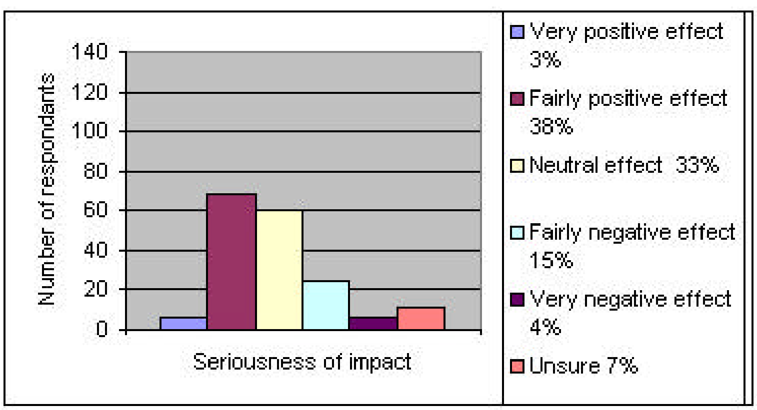


**Figure 24** Impact of scenario on regional water supply and demand

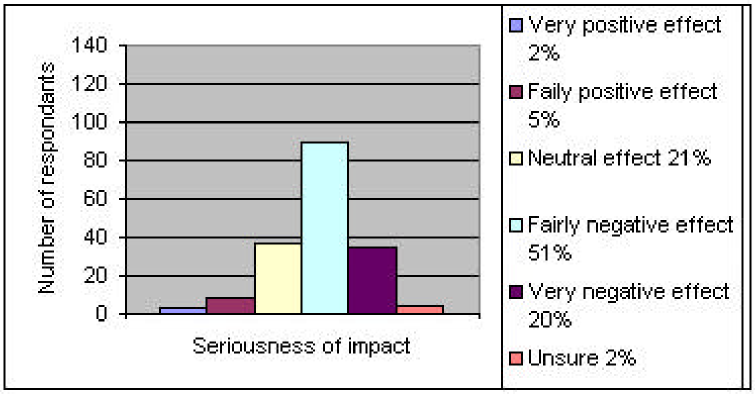



**Figure 25** Impact of scenario on waste water management

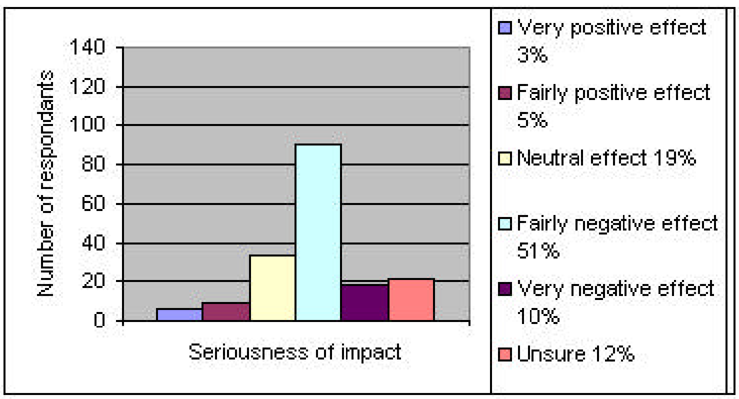



**Figure 26** Impact of scenario on urban areas

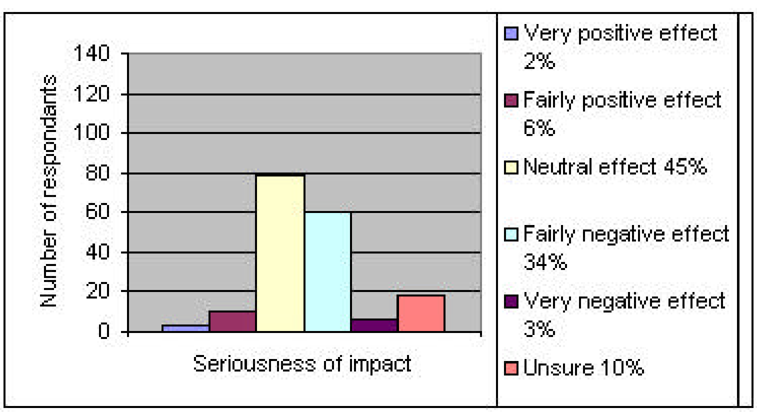


**Figure 27** Impact of scenario on the Peak District

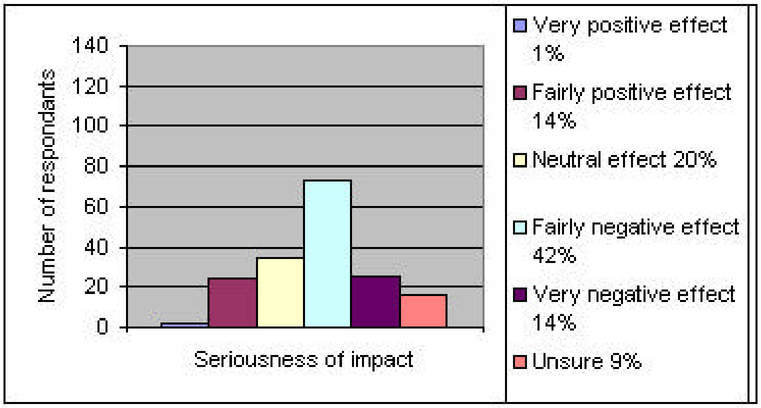



**Figure 28** Impact of scenario on agriculture and horticulture

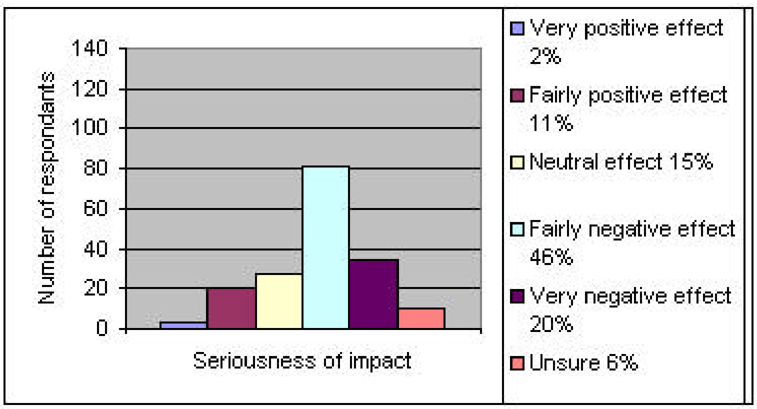



**Figure 29** Impact of scenario on lowland flooding

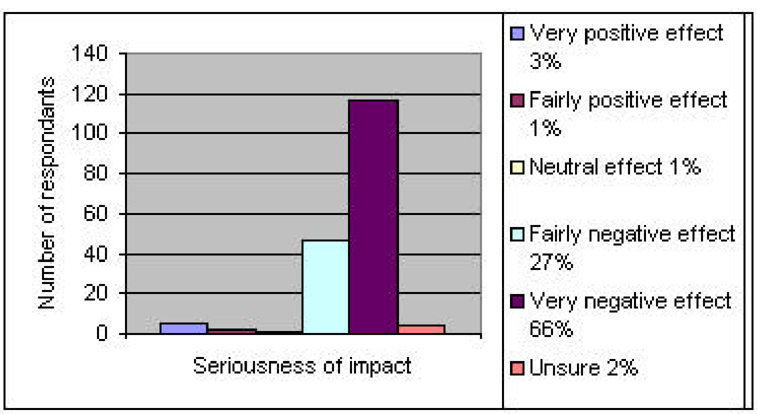


**Figure 30** Impact of scenario on forestry

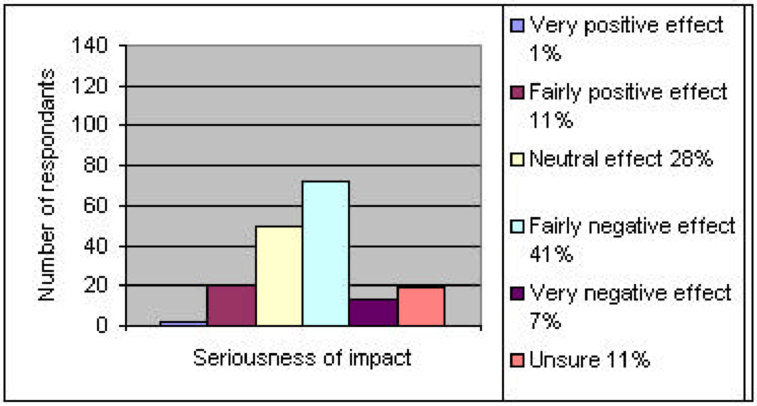



**Figure 31** Impact of scenario human health

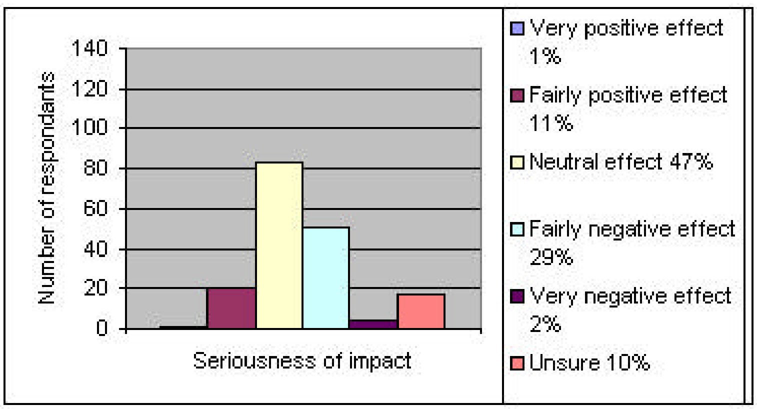



**Figure 32** Impact of scenario on working conditions

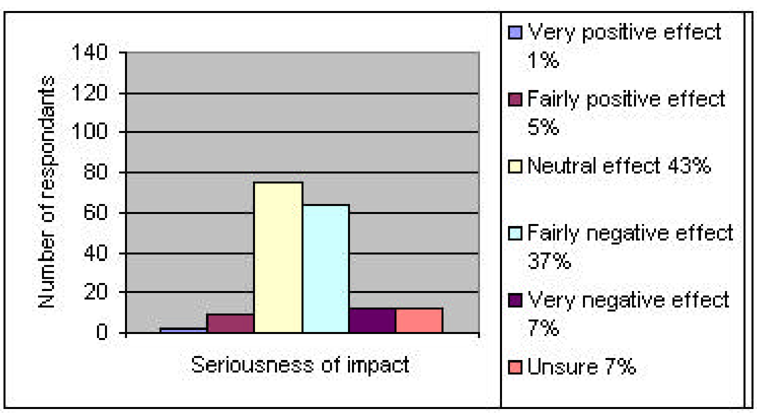


**Figure 33** Impact of scenario on manufacturing

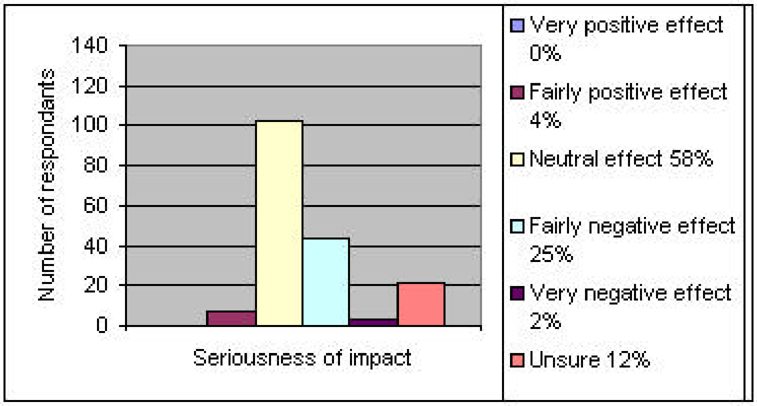



**Figure 34** Impact of scenario on services and retail

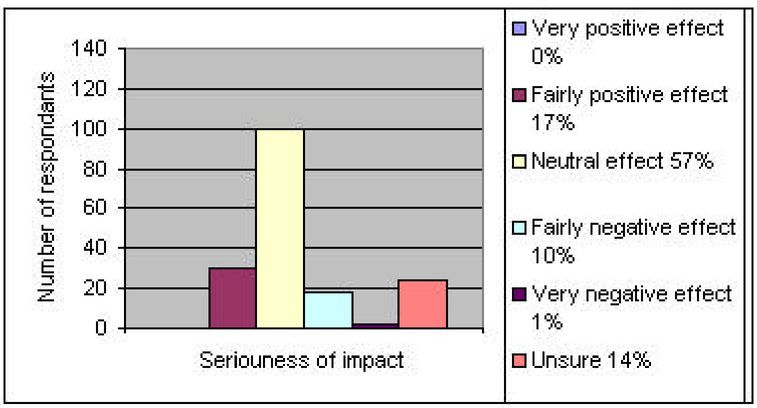



**Figure 35** Impact of scenario on the regional economy as a whole

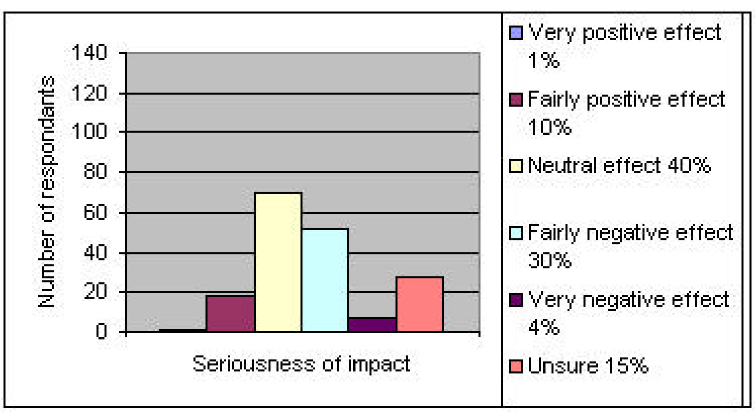


**Figure 36** Impact of scenario on insurance

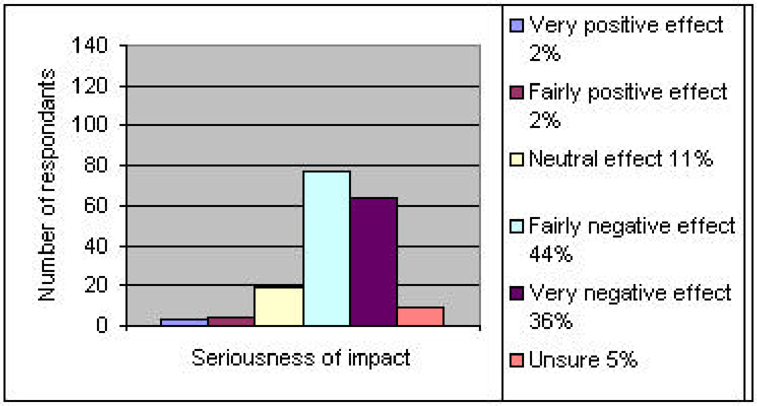



**Figure 37** Impact of scenario on tourism

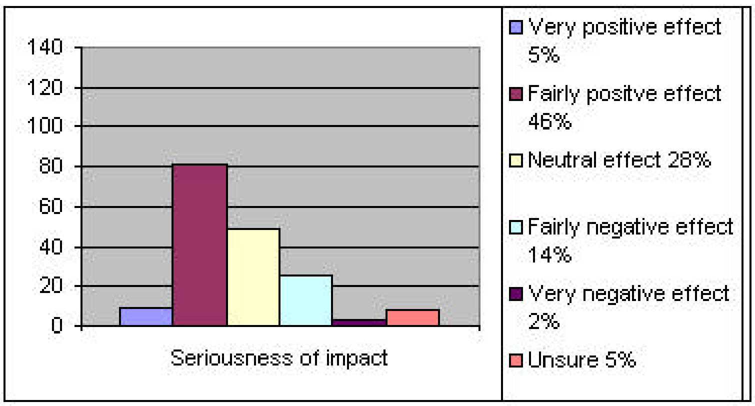



**Figure 38** Impact of scenario on public perceptions

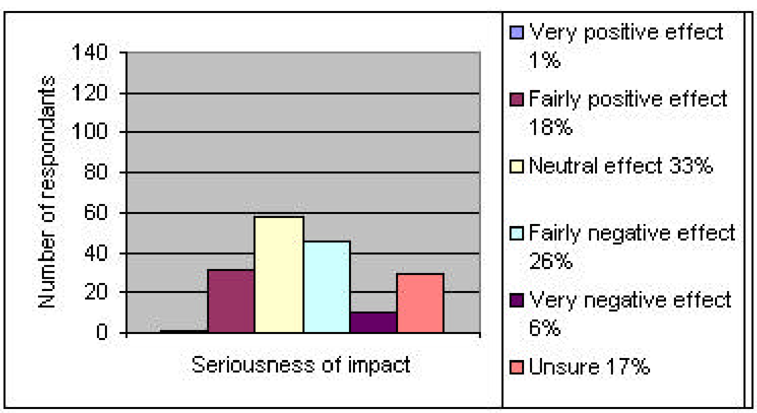


**Figure 39** Impact of scenario on transport

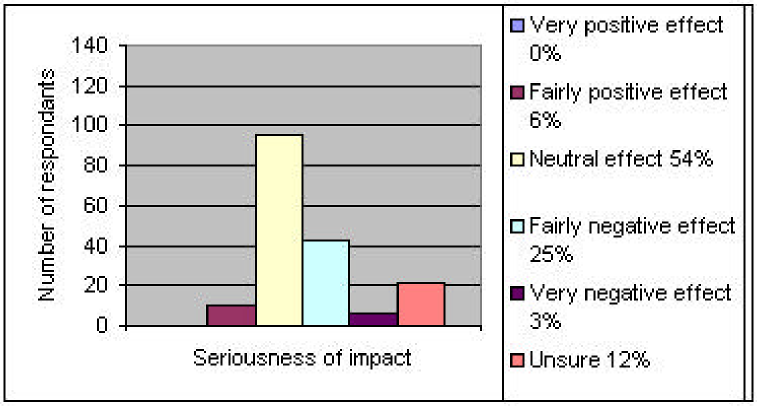



**Figure 40** Impact of scenario on buildings

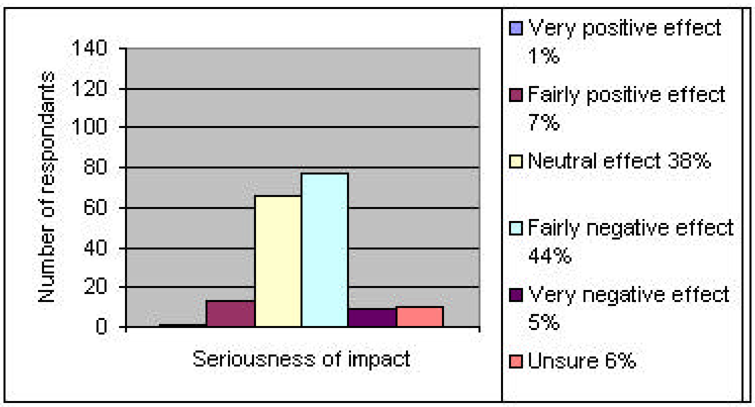


**Figure 41** 10 impacts ranked in order of seriousness

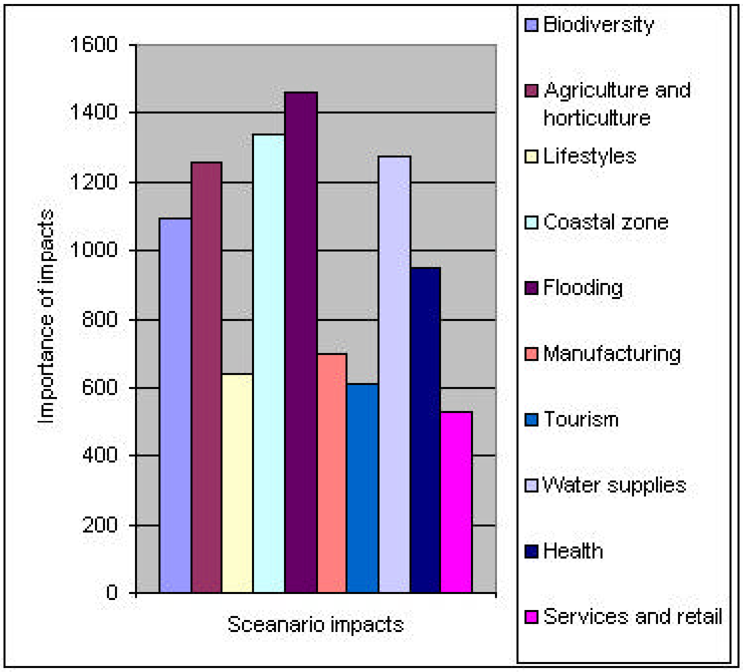



**Figure 42** Range of responses to scenarios for 20 sectors

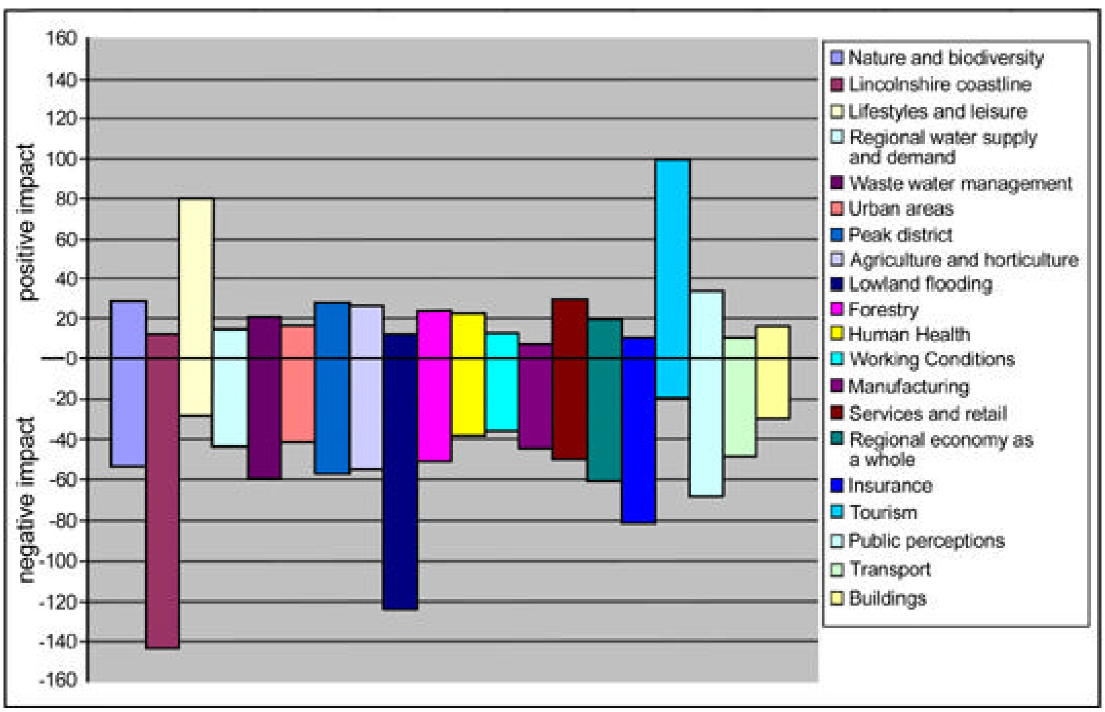


**Figure 43** Instruments for reducing carbon dioxide

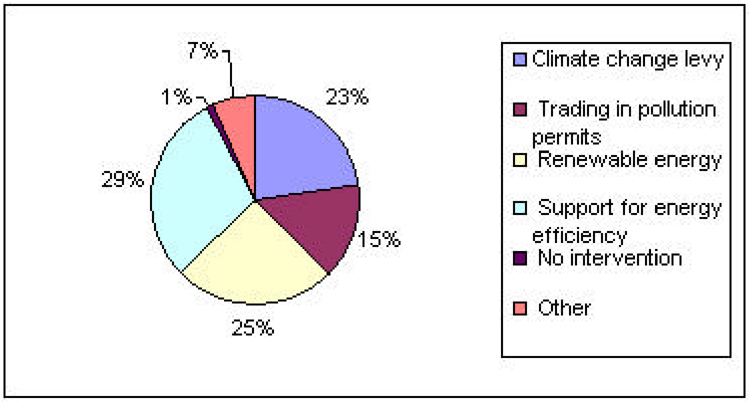
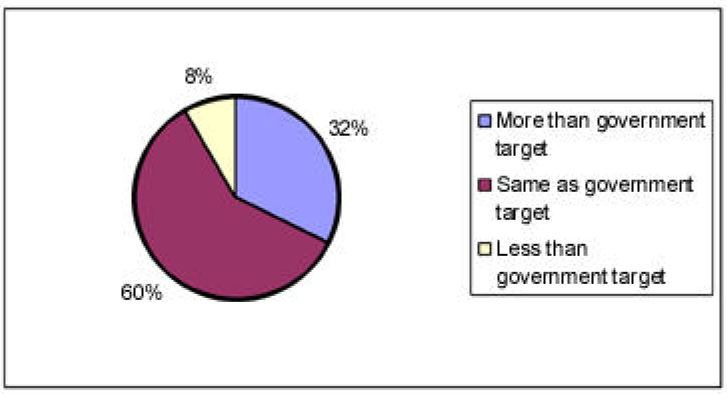



**Figure 44** East Midland regional targets



## 6.2 Comparison of responses between business and non-business respondents

94 business people answered the questionnaire, compared to 90 non-business people.

**Section 1 Climate change impacts ranked in order of seriousness for the region**

**Figure 45** Chart showing business responses for each sector

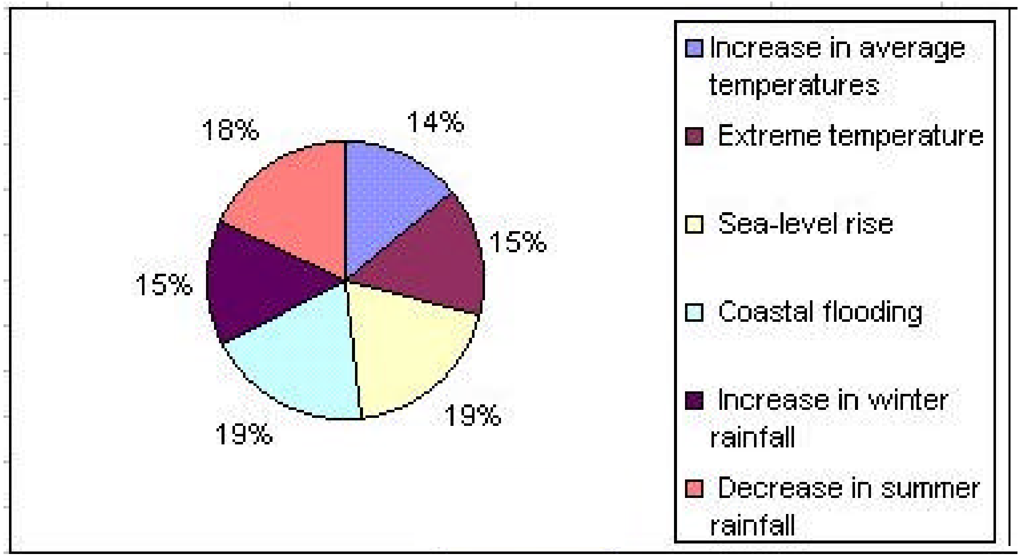


**Figure 46** Chart showing non-business responses for each sector

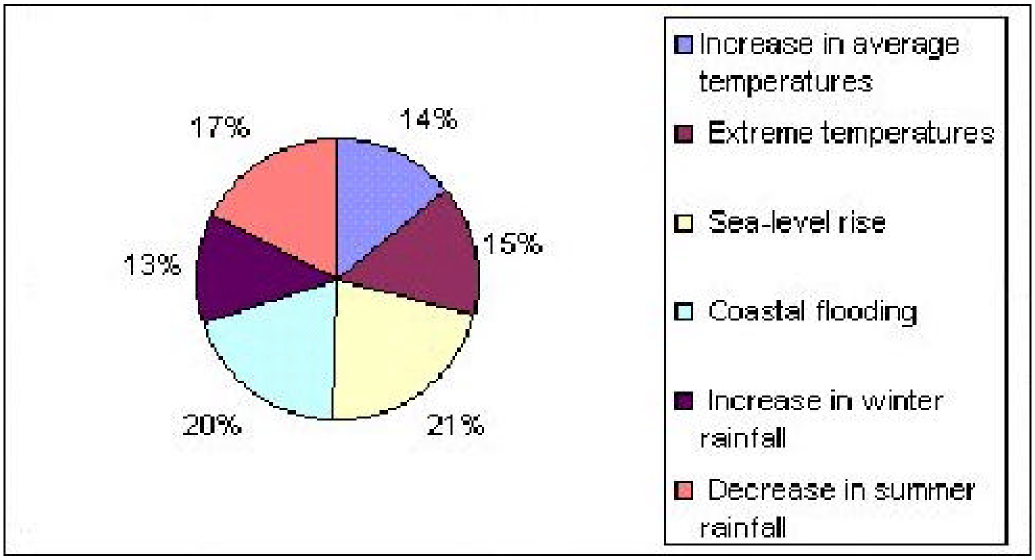



**Figure 47** Chart showing business responses for each sector

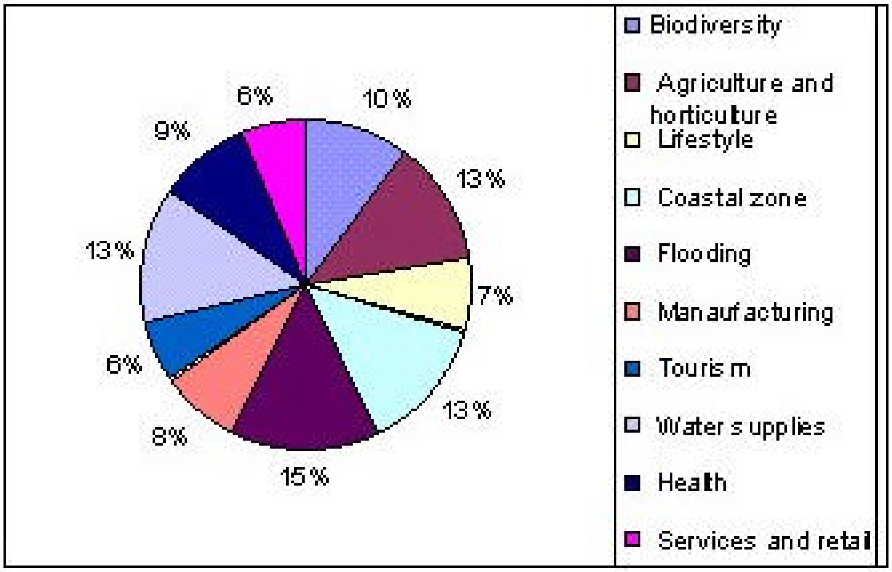
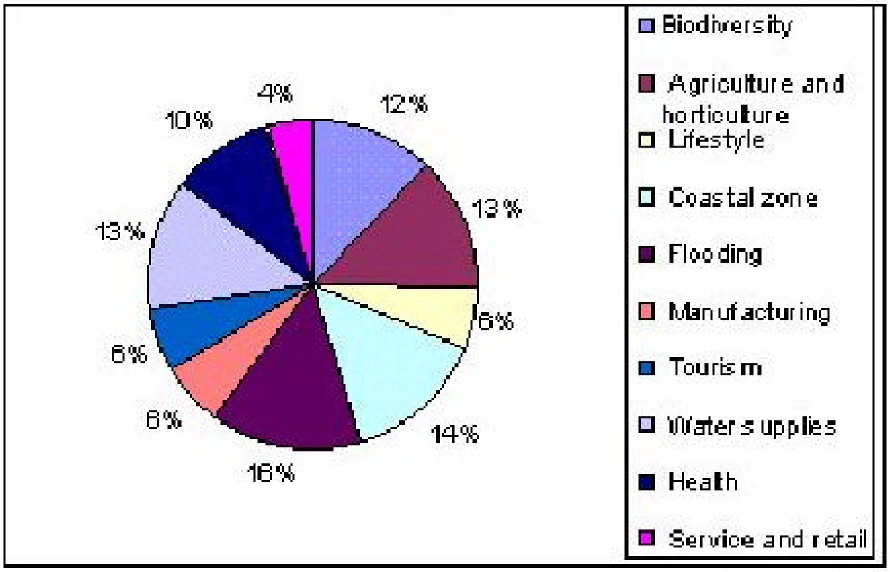


**Figure 48** Chart showing non-business responses for each sector




**Measures to reduce emissions of carbon dioxide within the region**

**Figure 49** Chart showing business responses for each sector

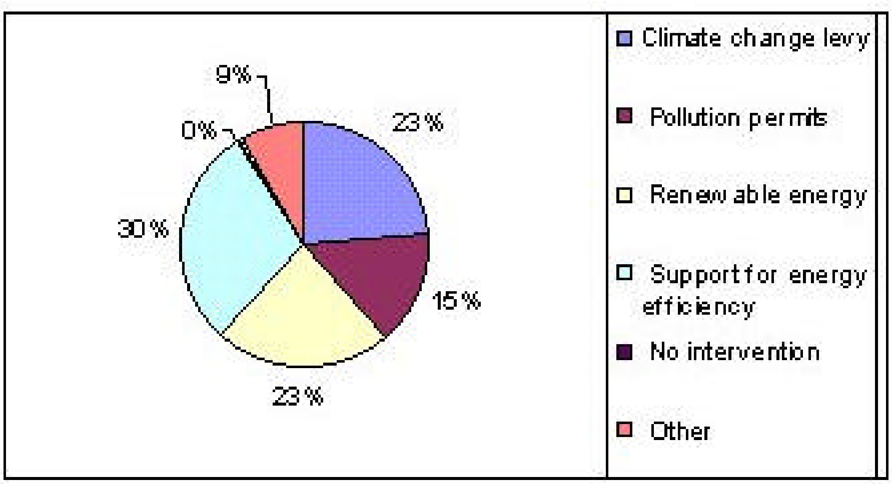
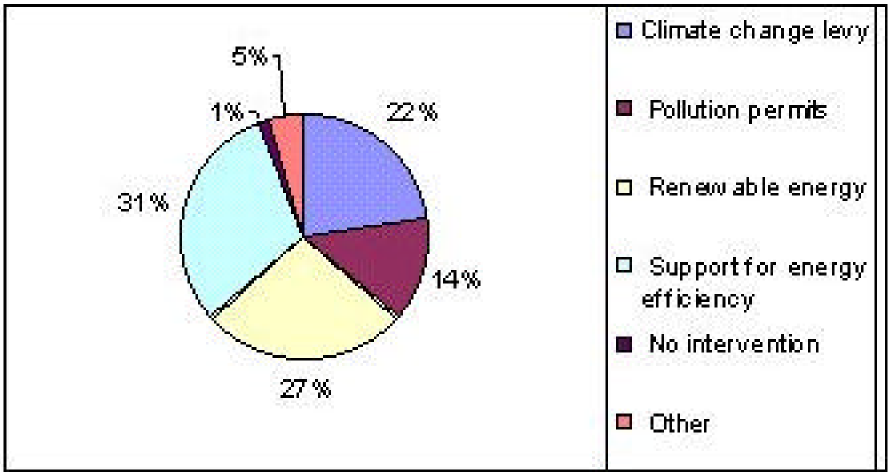


**Figure 50** Chart showing non-business responses for each sector




**Emissions reduction target**

**Figure 51** Chart showing business responses

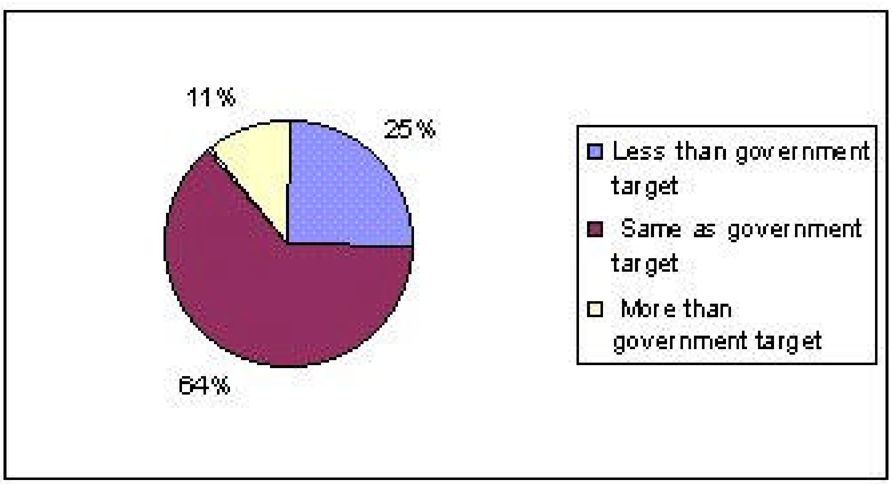
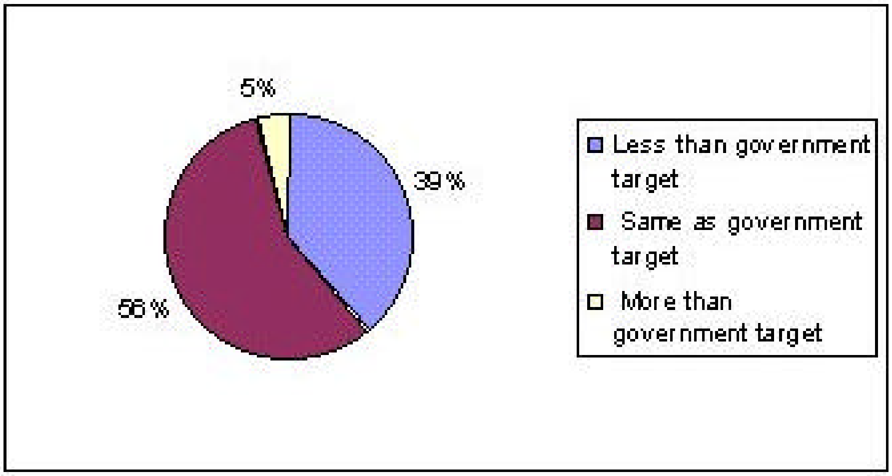


**Figure 52** Chart showing non-business responses




## East Midland regional issues

**Figure 53** Chart showing business responses for each sector

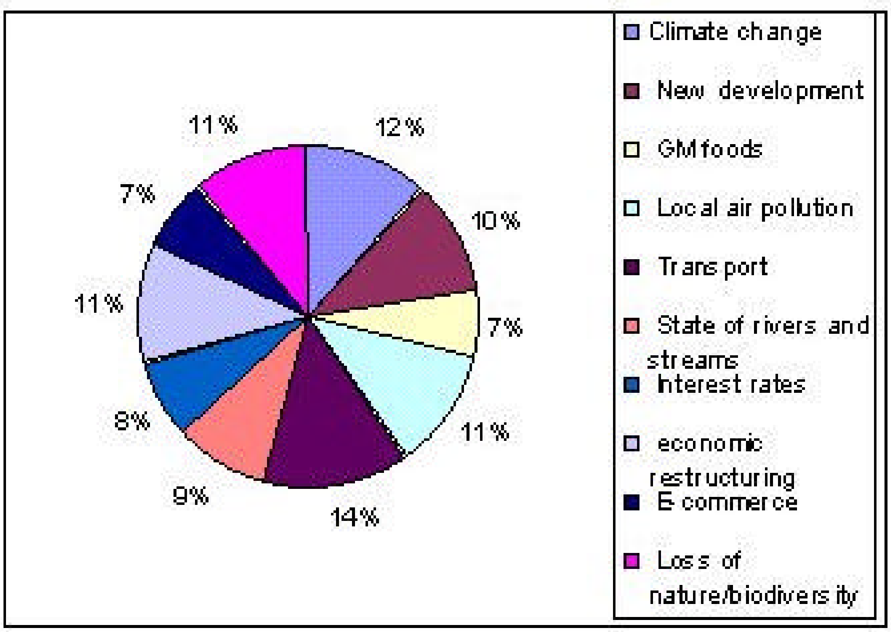
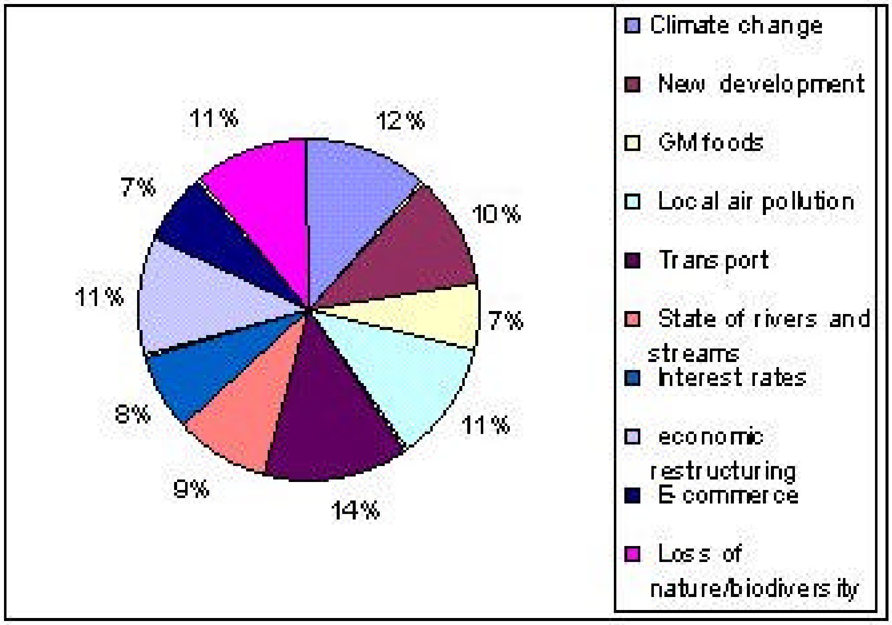


**Figure 54** Chart showing non-business responses for each sector




## 6.3 Results from a Set of Five Workshops

Stakeholder workshops were held in 4 locations in the Region: Buxton, Skegness, Northampton and Nottingham. In addition, a fifth workshop was held in Nottingham involving representatives of the Environment Agency's different functions from throughout the East Midlands region. In each case, between 6 and 12 individuals attended representing the public, private and NGO sectors. At each workshop, the results from the climate model downscaling presented in chapter 4 were presented, followed by a question and answer session. The key impacts, the nature of the vulnerability and identification of possible adaptation responses, were then analysed. The workshops lasted from 1.5 to 3 hours. The notes from the workshops are included as an appendix to this report. They have been circulated for comment and correction to the workshop participants. The key issues raised in each workshop are shown in the table below.

Amongst the participants were the following organisations: Flood Alert (Northampton), Environment Agency, FRCA (MAFF), Church's Shoes, Lincolnshire Wildlife Trust, East Lindsay Internal Drainage Board, Skegness Chamber of Commerce, Peak District National Park Authority, Derbyshire County Council, Nottingham City Council, Nottinghamshire County Council, Greater Nottingham Business Alliance, Green Network (Nottingham), CPRE, Buxton Climate Change Impacts Laboratory (Sheffield University), Gusto Construction, Greater Nottingham Business Alliance, Countryside Agency, the National Trust, Anglian Water and the Loss Prevention Council. Approximately 30 individuals in total participated in the Workshops.

**Table 22 The Key Issues Discussed in Each Stakeholder Workshop**

| Buxton | Nottingham | Skegness | Northampton |
|---|---|---|---|
| Upland impacts | Urban impacts | Coastal zone impacts | Flood risks and impacts |
| Biodiversity | Communities | Sea defences | Flood protection |
| Agriculture and vegetation | Buildings and Built Infrastructure | Biodiversity | Developments in the flood plain |
| Erosion | Parks and gardens | Extreme events | Public perceptions and responses |
| Water resources | Impacts on SMEs | Coastal zone development | Insurance issues |
| Flooding | Impacts on large firms | Tourism and recreation | Inland waterways |
| Tourism | Lifestyles and recreation | Ports and harbours | Impacts on SMEs |
| Transport | Biodiversity | Inland waterways | Impacts on large firms |
| Lifestyles | | | Local economy |
| Local economy | | | Transport |

In addition to the workshops, three further meetings have been held between members of the project team and key organisations: the RSPB (Solihull), SevernTrent Water (Birmingham) and PowerGen (Coventry). The findings from these meetings have been used in preparing chapter 5.

### 6.3.1 The Environment Agency

The key points arising from a discussion with the Environment Agency are provided below:

- The future frequency of distribution of storms, intense rainfall events and surges remains uncertain;
- The estimated return period for storms and floods are problematic: they are not the best means to present the average expected frequency to the general public. The credibility of the EA is reduced when the return period of a storm or flood is 100 years and such flooding occurs four times in six months - as was the case in Sileby, Leicestershire;
- Two approaches were discussed vis-à-vis flood protection: protecting against a given probability of the event occurring; and protecting against the worst observed event. Whilst the two approaches are related, they are not in practice the same and both have different ways of thinking about how to incorporate future climate change;

- A fall in baseflow to zero will cause drying out of soils in summer, when demand reaches its peak;
- Wetter winters will lead to increasing recharge of some aquifers - but whilst groundwater may contribute additional recharge, the situation is unlikely to improve because licensing exceeds current recharge;
- The EA cannot license additional water abstraction;
- Low riverflows can lead to the drying out of grass and other soil material and leaving the riverbanks liable to erosion; and
- High runoff after a dry event causes pollution to be washed into the river system, which would have low level during dry periods. Pollution levels are mostly from roofs roads and factories rather than sewage. Pumped oxygen helps to remedy a low oxygen content in rivers, as low flow levels can lead to problems with eutrophication and, near coasts, saline intrusion.

### 6.3.2 Highlights from Workshop in Buxton

- Some species in the Peak are at the limits of their southerly or northerly distribution. Prominent examples such as Jacob's Ladder are likely to disappear from the Peak District due to higher temperatures and lower summer rainfall. Other species such as the stemless thistle may well see an expansion. These species could be used as regional indicators of climate change.
- The uplands are very sensitive to increased erosion from intense rainfall events, upland fires and increased agricultural pressures, eg from grazing. These are already major pressures upon highly sensitive upland systems.
- Transport is a key problem in the Peak and if climate change (along with other social trends) extends the tourist season further into the autumn and winter, this will exacerbate the problem of car-based travel in addition to placing further stress on fragile ecosystems which have in the past been largely free of disturbance in winter.
- At a regional scale, initiatives to divert tourism to the areas between the coastal zone and the Peak are already underway and will need to be further developed in response to climate change. These 'buffer zones' should themselves benefit from climate change in terms of their attraction to the visitor.
- Climate change will increase the potential for intensive agriculture in lower areas of the Peak - accelerating a trend which is already taking place. The negative effects versus benefits will have to be carefully evaluated - and issues such as habitat corridors planned for and implemented appropriately.
- There are no immediately apparent negative impacts of climate change upon businesses.

### 6.3.3 Highlights from Workshop in Nottingham

- Builders and developers have not traditionally taken due account of climate change - either in terms of reducing water demand of households by having rainfall collection systems (which also provides greater buffering against floods), or in terms of reducing energy consumption through insulation and passive solar design, etc. Design of sustainable buildings will need to take account of changes in rainfall patterns - eg larger interception tanks would be required for more intensive winter rainfall. The whole issue of how urban and building design can be organised to reduce run-off and therefore potential flooding, is very undeveloped in the UK, though it is commonplace in other countries, such as Germany and the USA.

- Before the business community responds to climate change, it will need to have much better knowledge of the probabilities of different scenarios occurring. It is not good enough just to present 4 scenarios without some indication of likelihood. Also, the business community will have to consider very carefully just how important climate change is relative to other types of change - many of which are much more imminent and short-term. Finally, the future pattern of the business sector will be quite different from today's - eg manufacturing in Greater Nottingham will probably contract from 23% to about 12%.

### 6.3.4 Highlights from Workshop in Skegness

- The trend in tourism is towards more all-year round leisure and recreation. Climate change will enhance this trend and will thus present a major opportunity to coastal resorts in the East Midlands.

- There will be impacts on nature reserves such as Gibraltar Point, where the coastline will change. However, this - and managed retreat initiatives around the Wash - could provide new opportunities for biodiversity. New species of birds and insects and plants will emerge.

- The internal land drainage board in the Region face particular problems from climate change - in particular in relation to more intensive rainfall events increasing the risk of flooding and putting more stress on the drainage system (and increasing energy costs through pumping). Projections of changes in intense rainfall events need to be analysed using the models employed in designing drainage. Land drainage systems can also play a major role in alleviating flooding in urban areas, and in water storage in summer.

### 6.3.5 Highlights from Workshop in Northampton

- The flooding in April 1998 has led to a new awareness of the risks and impacts of flooding in Northampton. Companies such as Church's Shoes were heavily affected, and many households have been adversely impacted. Indeed, some individuals appear to suffer a post-traumatic stress syndrome as a result of flooding.

- The insurance industry needs to improve its handling of claims when major episodes such as Northampton occur. At present, they are uncoordinated and do not share resources, so increasing overall costs by a large amount. Also, they are not good 'on the ground' in helping individuals fill in forms and get claims expediently through the claims system.

- Improvements to flood defence in Northampton appear to take a long time to be implemented. The insurance industry may benefit itself from contributing to the upfront costs of higher protection, given that future risks are thereby limited.
- Working conditions in factories in Northampton are already affected by overly high temperatures, encouraging some firms to request that some workers modify their work patterns - eg starting earlier or later. Continuation of this trend (increased temperatures) is viewed with trepidation given the difficulty of changing working temperatures in old factories.

### 6.3.6 Conclusions

The above discussions touched on a wide range of environmental, social and economic issues that stakeholders feel could be related to climate change. This is based on observed trends eg water abstraction, tourism, agriculture and biodiversity and recent events eg Northampton floods and upland fires. A number of responses to climate related issues were highlighted eg supplementary planning guidance for development in the floodplain and different approaches to flood defence. The workshops also identified a number of opportunities for the Region eg increased tourism, design and building of sustainable and use of sustainable water practices.

Some concerns were also expressed eg the need for more precise information by the business community for use in planning and the slow response to flood events in Northampton. These views were used to inform the assessment of potential climate change impacts and adaptations in the Region (see Chapter 5).

# 7. Greenhouse Gas Inventory

*Main Author: Dr Paul Fleming, DeMontfort University*

## 7.1 Summary

An inventory of greenhouse gas emissions has been determined for the six main greenhouse gases - carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride ($SF_6$) emitted by source from the East Midlands in 1997. This is approximately 60 million tonnes of $CO_2$ equivalent, or an estimated 14.2 tonnes of carbon dioxide equivalent per person per year.

The Region's production of nearly 60 million tonnes of $CO_2$ equivalent of these gases represents approximately 8.7% of UK emissions. This is higher than might be expected by considering the percentage of the UK population in the East Midlands (7%), but occurs because of electrical power generation in the Region which is exported to other regions.

Over 80% of the Region's greenhouse gas emissions are related to the use of energy (about 46% from power station emission, 14% from road transport, 14% from domestic, and business fuel use and 7% from industrial fuel use). The remaining emissions include non-livestock agriculture (4%), coal mines and gas transmission and distribution (3%), landfill sites (2%) and livestock (2%). $CO_2$ emissions contributed 86% of total regional greenhouse gas emissions, while $CH_4$ and $N_2O$ emissions were 7% and 5% of total emissions respectively. HFCs, PFCs and $SF_6$ contribute less than 2% of emissions. Emissions of HFCs are primarily from refrigeration/air conditioning and aerosols (including metered dose inhalers), while PFC emissions are mainly from electronics and refrigeration and $SF_6$ emissions are from magnesium manufacture, electrical insulation and electronics and the cushioning in the soles of training shoes..

The inventory was compiled using a combination of national and regional data. Complete regional data for all greenhouse gases is not readily available.

The major source of greenhouse gases is from the use of fossil fuels accounting for almost 90% of the Region's emissions. Sufficient data on electricity, gas, oil and solid fuel consumption in the Region has not been readily available to estimate regional greenhouse gas emissions. Utilities should be encouraged to supply such data from which regular monitoring of progress towards greenhouse gas emission reduction targets will then be possible. Without such data it will be virtually impossible to monitor the Region's progress.

The Region has many European and nationally recognised examples of good practice in reducing $CO_2$ emissions. These individual examples should be replicated on a wider scale across the Region. The Regional Assembly and Regional Development Agency as well as the constituent local authorities, businesses and households should put in place measures to reduce greenhouse gas emissions. Examples of such measures currently implemented in the East Midlands are given.

The Region now needs to set a target for emissions reduction, establish data collection procedures to monitor progress towards this target, and ensure that energy efficiency and renewable energy measures are integrated into all policy areas.

## 7.2 Introduction

The inventory of greenhouse gas emissions for the East Midlands was completed using the limited available data on emissions for the Region and by estimating regional emissions from national figures using different scaling factors.

The greenhouse gas emissions inventory for the East Midlands has been compiled for six gases for 1997 (the most recent year that necessary data was available). These gases are included in the UK's greenhouse gas emissions reduction target resulting from the Kyoto climate change summit (12.5% below 1990 levels by 2008-2012). The six major greenhouse gases, and their major sources in the UK, are given in Table 23.

**Table 23 Types and Sources of Greenhouse Gases**

| Greenhouse Gas | Source |
|---|---|
| Carbon dioxide ($CO_2$) | Combustion of fossil fuels in power stations, road transport, domestic sector, industrial sector, and commercial, public and agricultural sectors |
| Methane ($CH_4$) | Agricultural livestock, landfill sites, leakage from the gas distribution network, and coal mines |
| Nitrous oxide ($N_2O$) | Non-livestock agriculture (eg agricultural soils), nylon and nitric acid production, power stations, and road transport combustion |
| Hydrofluorocarbons (HFCs) | Halocarbon production, refrigeration, and aerosols |
| Perfluorocarbons (PFCs) | Electronics industry and aluminium production |
| Sulphur hexafluoride ($SF_6$) | Magnesium manufacture and electrical insulation |

Carbon dioxide emissions form the largest share of East Midlands greenhouse gas emissions (86%) with methane and nitrous oxide emissions contributing approximately 7% and 5% respectively. HFCs, PFCs, and sulphur hexafluoride contributed less than 2% of emissions.

The following gives details of the main sources for each gas:

- Carbon dioxide: The main sources are the combustion of fossil fuels in power stations (53% of carbon dioxide emissions), road transport (16%), the domestic sector (12%), the industrial sector (8%), and commercial, public and agricultural sectors (4%);
- Methane: The main sources are coal mines (31% of methane emissions), landfill sites (26%), livestock (enteric fermentation) (21%), and leakage from the gas distribution network (12%);

- Nitrous oxide: The largest sources are non-livestock agriculture (eg agricultural soils) (73% of nitrous oxide emissions), power stations (12%), and road transport combustion (8%);
- Hydrofluorocarbons: Nationally, in 1997, the largest source of HFC emissions has been associated with the manufacture of HCFCs and HFCs. In the East Midlands, the main sources are refrigeration/air conditioning (50% of HFC emissions) and aerosols (including metered dose inhalers) (49%);
- Perfluorocarbons: Sources are electronics (and training shoes) (95% of PFC emissions), and refrigeration (5%). Nationally, another significant source is in connection with aluminium production; and
- Sulphur hexafluoride: Sources are magnesium manufacture (74% of $SF_6$ emissions) and electrical insulation, electronics and trainers (26%).

The greenhouse gas emissions inventory has been compiled in terms of emissions sources rather than end use sectors. This is because since more detailed emissions information by source is available, enabling a greater disaggregation of regional greenhouse gas emissions.

Emissions of carbon dioxide have been given in tonnes of carbon (as used by the government for carbon dioxide emissions) and other emissions have been given in tonnes of each gas. Also, the emissions have been expressed in terms of their tonnes of carbon dioxide equivalent.

## 7.3 Greenhouse gas emissions data

The emissions of greenhouse gases from the East Midlands are estimated to be approximately 59.1 million tonnes $CO_2$ equivalent in 1997. (This compares with UK emissions of 679 Mt $CO_2$ equivalent for similar source categories to those used by the National Environmental Technology Centre (NETCEN, 1999a). The NETCEN, rather than the Intergovernmental Panel on Climate Change (IPPC), basis has been used. The IPCC uses a slightly different approach, (eg for land use change). A summary of the estimated emissions of each greenhouse gas is given below in Table 24, and a detailed breakdown of emissions by source are given in section 7.8.

**Table 24 East Midlands greenhouse gas emissions, by gas**

| Gas | 1997 East Midlands Emissions (tonnes of gas) | 1997 East Midlands Emissions (kt $CO_2$ equivalent) |
|---|---|---|
| Carbon dioxide | 13,868 kt carbon | 50,848 |
| Methane | 210 kt $CH_4$ | 4,414 |
| Nitrous oxide | 9,324 t $N_2O$ | 2,890 |
| Hydrofluorocarbons | 120.9 t HFC | 727 |
| Perfluorocarbons | 4.2 t PFC | 29 |
| Sulphur hexafluoride | 6.2 t $SF_6$ | 148 |
| **Total emissions** | | **59,058** |

The data is also presented in terms of $CO_2$ equivalent. This is calculated using global warming potentials. The use of global warming potentials in greenhouse gas emission inventories enables emissions figures to be obtained that allow for the relative global warming influences of the gases. The data for the East Midlands has been converted using global warming potentials to give emissions of each gas in terms of their carbon dioxide equivalent, as shown in Tables 27 and 29. The conversion factors used, based on NETCEN (1999a) figures, are as follows:

**Table 25 Conversion factors used to convert emissions to kt $CO_2$ equivalent**

| Gas | Global warming potential (100 years) | Units in Tables 3 & 5 | Conversion factor to kt $CO_2$ equivalent |
|---|---|---|---|
| $CO_2$ | 1 | Kt carbon | 3.67 |
| $CH_4$ | 21 | kt | 21 |
| $N_2O$ | 310 | t | 0.31 |
| HFC | 560-12,100 | T | 6.01 |
| PFC | 6,000-7,400 | T | 6.96 |
| $SF_6$ | 23,900 | T | 23.9 |

## 7.4 Emissions estimation methods

Regional greenhouse gas emissions figures have been estimated using actual emissions data in a limited number of cases where available. However most data was derived by scaling from national figures, since a significant proportion of East Midlands greenhouse gas emissions data at the local level are not generally available. Whilst some local data have been available, and have been used (eg details of carbon dioxide emissions from power stations in the Region), other data is incomplete. For example, it is possible to calculate emissions by multiplying data relating to the amount of a particular activity (such as fuel use) with the corresponding emissions factor (eg greenhouse gas emissions per unit fuel use) (eg NETCEN, 1999a), if the necessary data is available. Such available data was gas consumption data for the Transco East Midlands local distribution zone (for customers below 73,200 kWh per year demand) and data on electricity distributed in the East Midlands Electricity area (excludes power sold directly to customers via high voltage line) which is available via the Digest of UK Energy Statistics. However this represented a small proportion of total regional energy.

In the absence of appropriate data for the Region, almost all emissions were estimated by multiplying different pro-rata factors (derived from a range of national and regional data) by national emissions data (from the UK National Air Quality Information Archive and the National Atmospheric Emissions Inventory). For example, UK carbon dioxide emissions from a certain source can be multiplied by, say, the ratio of regional and national population to obtain an estimate of regional emissions (eg Lindley et al, 1996, and UMIST, 1999). The scaling factors and assumptions used are outlined in section 7.8.

## 7.5 Data Used In Determining Emissions

Regional and national data on population, number of households, gross domestic product, number of cars licensed, agricultural land area and livestock numbers, aircraft and shipping cargo movements has been obtained from the Government statistical publications “Regional Trends”, and “Transport Statistics Great Britain”. Also, regional and national waste disposal information, and coal production data from the Environment Agency and The Coal Authority respectively has been used.

Information is available from national, regional and sub-regional organisations, including the Department of the Environment, Transport and the Regions, the Environment Agency (including emissions from major industrial sites), utilities, and local authorities (eg energy consumption in municipal buildings, local energy consumption information, energy consumption in housing from Home Energy Conservation Act report). The Regional Observatory was also contacted for information but, as yet, no relevant information has been available.

## 7.6 Uncertainty

The accuracy of the estimates depends on the accuracy of the national emissions inventory data that has been used, and on the reliability of the pro-rata estimates. Estimated uncertainties for the national data given in the National Atmospheric Emissions Inventory 1997 Report are: carbon dioxide +/- 4%, methane +/- 17%, nitrous oxide -55% to +234% (‘skewed uncertainty distribution’), HFCs +/- 25%, PFCs +/- 20%, SF +/- 13%. The uncertainty in the pro-rata estimates is not known, although efforts have been made to limit this uncertainty through the selection of the scaling factors for different emission sources.

Several assumptions have been made in making the estimates. For example, it has been assumed that there is negligible iron and steel production in the East Midlands, and in relation to aircraft emissions East Midlands Airport is the only airport considered. It has been assumed that there is no halocarbon, or aluminium production in the East Midlands. Other assumptions were that there is no manufacture of adipic or nitric acid, and no oil refineries are located in the Region.

## 7.7 Monitoring future emissions

In order to measure the Region’s progress towards greenhouse gas emissions reduction targets, monitoring will be essential. This monitoring should be based on data from:

- scaling national emissions data to the regional level. This approach is dependent on the scaling factors used and is not particularly sensitive to changes at the regional scale;
- available regional data. For example, regional power station emissions could be monitored using Environment Agency emissions data and/or data from individual power stations. Environment Agency data on annual emissions from specific large industrial sites could be monitored. Some indication of emissions trends related to the combustion of fuels in the domestic, public, commercial, and industrial sectors could be obtained

through monitoring changes in the gas use data that is available (eg DTI, 1999b). Also, electricity distributed data for the East Midlands Electricity area (see DTI, 1999b) could be monitored; and

- Periodic sample surveys of key factors affecting emissions (eg energy use, travel, etc.) could be undertaken.

If energy use data (eg on a postcode basis) was available for the Region for electricity and gas, a significant proportion of greenhouse gas emissions could be estimated, using an end user approach. Emissions associated with the generation of electricity that is used in the Region could be calculated. (It is anticipated that these would be less than the emissions from power stations in the Region as electricity generated from the above average concentration of power stations is used outside the Region.) The electricity and gas utilities should be encouraged to provide such data.

## 7.8 Greenhouse gas emissions by source

The following section present the Region's greenhouse gas emissions in pictorial and tabular form.

Figure 55 is a pie chart of greenhouse gas emissions for the East Midlands expressed as thousands of tonnes of $CO_2$ equivalent.

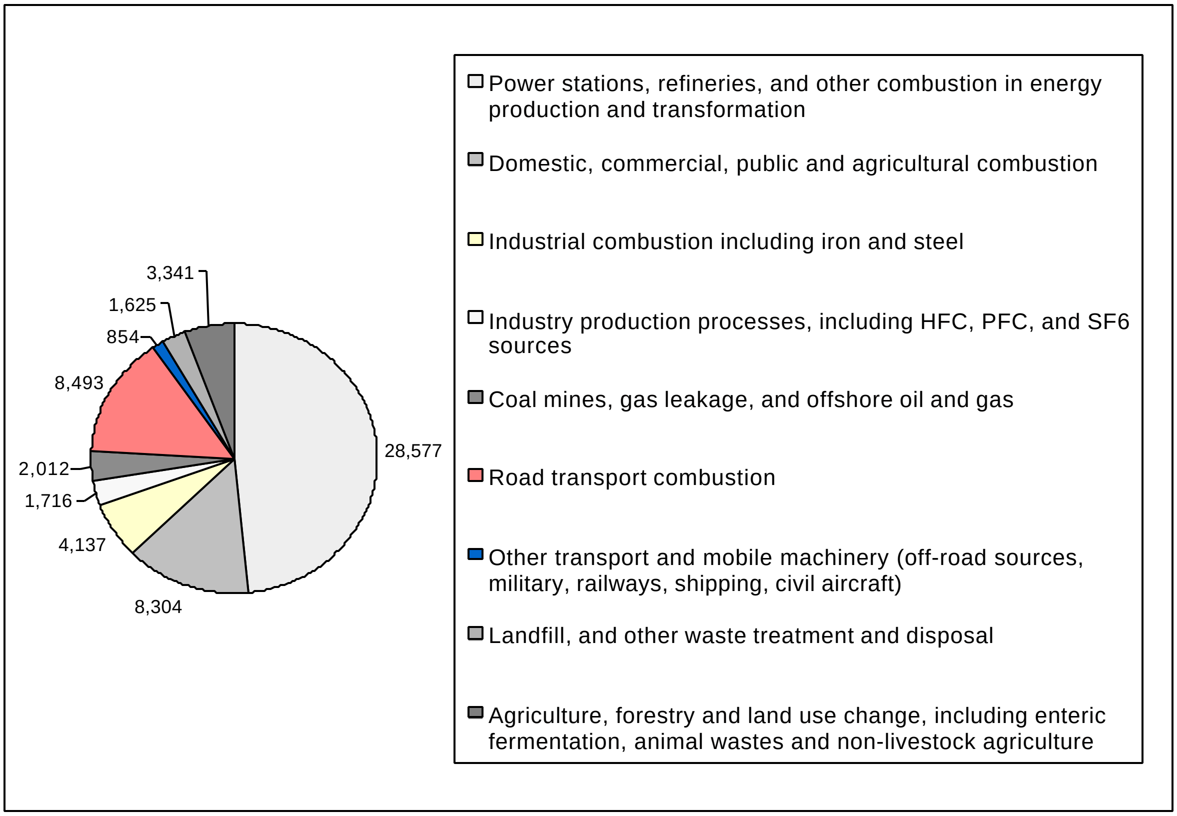



**Figure 55. East Midlands Greenhouse Gas Emissions by Source (1997) (kt $CO_2$ equivalent)**

Figure 56 shows the energy-related greenhouse gas emissions. These account for almost 90% of the Region's $CO_2$ equivalent emissions.

**Figure 56 Energy related greenhouse gas emissions**

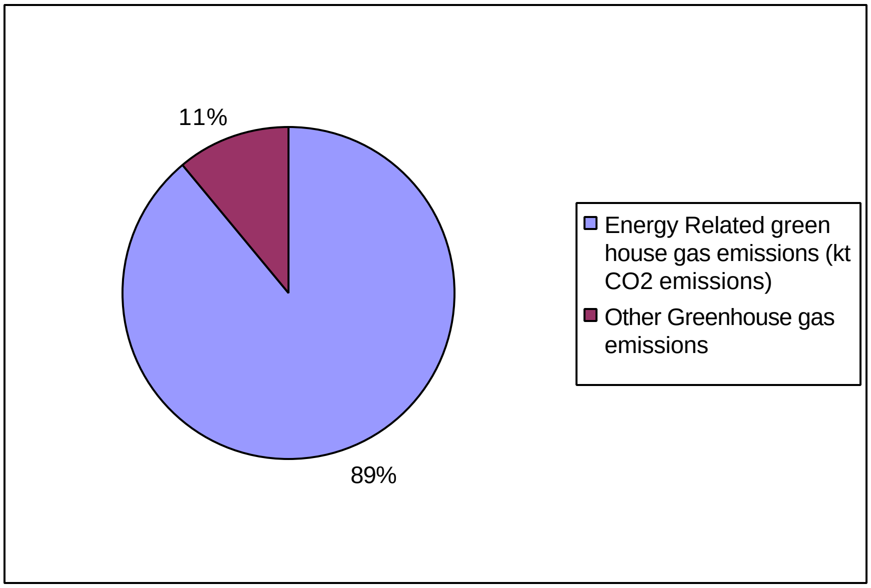



Table 26 summarises the estimates of greenhouse gas emissions by source for the East Midlands for 1997. Figures are in tonnes of the appropriate gas and a comparison of the Region's emissions with UK emissions is also presented.

Table 27 summarises the estimates of greenhouse gas emissions by source for the East Midlands for 1997, in terms of thousands of tonnes of carbon dioxide equivalent. Emissions by source are also given as a proportion of total East Midlands greenhouse gas emissions.

Table 28 gives detailed information on greenhouse gas emissions estimates for the East Midlands for 1997, and also UK emissions, by emission source. Figures are in tonnes of the appropriate gas.

Table 29 gives detailed information on East Midlands greenhouse gas emissions estimates by source for 1997, in terms of thousands of tonnes of carbon dioxide equivalent.

**Table 26 UK and East Midlands Greenhouse Gas Emissions by Source (1997) – Summary Table**

| Emission Source | Carbon Dioxide (kt carbon) | | | Methane (kt) | | | Nitrous Oxide (t) | | | HFCs (t) | | | PFCs (t) | | | $SF_6$ (t) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | UK | East Midlands | East Mids % of UK | UK | East Midlands | East Mids % of UK | UK | East Midlands | East Mids % of UK | UK | East Midlands | East Mids % of UK | UK | East Midlands | East Mids % of UK | UK | East Midlands | East Mids % of UK |
| Power stations, refineries, and other combustion in energy production and transformation | 50,695 | 7,681 | 15.2 | 20 | 3 | 15.7 | 6,500 | 1,120 | 17.2 | | | | | | | | | |
| Domestic, commercial, public and agricultural combustion | 31,644 | 2,244 | 7.1 | 39 | 3 | 7.1 | 800 | 57 | 7.1 | | | | | | | | | |
| Industrial combustion including iron and steel | 23,925 | 1,120 | 4.7 | 12 | 0 | 2.1 | 1,500 | 79 | 5.3 | | | | | | | | | |
| Industry production processes | 3,311 | 218 | 6.6 | 9 | 1 | 6.6 | 69,300 | 0 | 0.0 | | | | | | | | | |
| Coal mines, gas leakage, and offshore oil and gas | 171 | 12 | 7.0 | 737 | 94 | 12.7 | | | | | | | | | | | | |
| Road transport combustion | 31,729 | 2,243 | 7.1 | 21 | 1 | 7.1 | 10,800 | 764 | 7.1 | | | | | | | | | |
| Other transport and mobile machinery (off-road sources, military, railways, shipping, civil aircraft) | 4,344 | 214 | 4.9 | 2 | 0 | 7.0 | 3,000 | 211 | 7.0 | | | | | | | | | |
| Landfill, and other waste treatment and disposal | 1,546 | 109 | 7.0 | 883 | 58 | 6.6 | 500 | 35 | 7.0 | | | | | | | | | |
| Agriculture, forestry and land use change, including enteric fermentation, animal wastes and non-livestock agriculture | 367 | 27 | 7.3 | 1,004 | 50 | 5.0 | 98,800 | 7,057 | 7.1 | | | | | | | | | |
| HFC sources (halocarbon production, fire-fighting, electronics, foams, refrigeration, aerosols) | | | | | | | | | | 3,067 | 120.9 | 3.9 | | | | | | |
| PFC sources (fire-fighting, aluminium production, halocarbon production, refrigeration, electronics and training shoes) | | | | | | | | | | | | | 96 | 4.2 | 4.4 | | | |
| SF6 sources (magnesium manufacture, electrical insulation, electronics and training shoes) | | | | | | | | | | | | | | | | 53 | 6.2 | 11.8 |
| **TOTALS** | **147,731** | **13,868** | **9.4** | **2,726** | **210** | **7.7** | **191,200** | **9,324** | **4.9** | **3,067** | **120.9** | **3.9** | **96** | **4.2** | **4.4** | **53** | **6.2** | **11.8** |

Emissions of carbon dioxide are given in tonnes of carbon, and emissions of other gases are given in tonnes of each gas

**Table 27 UK and East Midlands Greenhouse Gas Emissions by Source (1997) (kt $CO_2$ equivalent) – Summary Table**

| | Carbon Dioxide | | | Methane | | | Nitrous Oxide | | | HFCs | | | PFCs | | | $SF_6$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Emission Source** | **UK** | **East Midlands** | **% of Total GHG in E. Midlands** | **UK** | **East Midlands** | **% of Total GHG in E. Midlands** | **UK** | **East Midlands** | **% of Total GHG in E. Midlands** | **UK** | **East Midlands** | **% of Total GHG in E. Midlands** | **UK** | **East Midlands** | **% of Total GHG in E. Midlands** | **UK** | **East Midlands** | **% of Total GHG in E. Midlands** |
| Power stations, refineries, and other combustion in energy production and transformation | 185,881 | 28,163 | 47.7 | 424 | 66 | 0.1 | 2,015 | 347 | 0.6 | | | | | | | | | |
| Domestic, commercial, public and agricultural combustion | 116,028 | 8,227 | 13.9 | 827 | 59 | 0.1 | 248 | 18 | 0.0 | | | | | | | | | |
| Industrial combustion including iron and steel | 87,726 | 4,108 | 7.0 | 246 | 5 | 0.0 | 465 | 24 | 0.0 | | | | | | | | | |
| Industry production processes | 12,139 | 799 | 1.4 | 185 | 12 | 0.0 | 21,483 | 0 | 0.0 | | | | | | | | | |
| Coal mines, gas leakage, and offshore oil and gas | 626 | 44 | 0.1 | 15,475 | 1,968 | 3.3 | | | | | | | | | | | | |
| Road transport combustion | 116,340 | 8,226 | 13.9 | 433 | 31 | 0.1 | 3,348 | 237 | 0.4 | | | | | | | | | |
| Other transport and mobile machinery (off-road sources, military, railways, shipping, civil aircraft) | 15,928 | 785 | 1.3 | 48 | 3 | 0.0 | 930 | 66 | 0.1 | | | | | | | | | |
| Landfill, and other waste treatment and disposal | 5,668 | 399 | 0.7 | 18,537 | 1,214 | 2.1 | 155 | 11 | 0.0 | | | | | | | | | |
| Agriculture, forestry and land use change, including enteric fermentation, animal wastes and non-livestock agriculture | 1,346 | 98 | 0.2 | 21,076 | 1,056 | 1.8 | 30,628 | 2,188 | 3.7 | | | | | | | | | |
| HFC sources (halocarbon production, fire-fighting, electronics, foams, refrigeration, aerosols) | | | | | | | | | | 18,433 | 727 | 1.2 | | | | | | |
| PFC sources (fire-fighting, aluminum production, halocarbon production, refrigeration, electronics and training shoes) | | | | | | | | | | | | | 668 | 29 | 0.05 | | | |
| SF6 sources (magnesium manufacture, electrical insulation, electronics and training shoes) | | | | | | | | | | | | | | | | 1,262 | 148 | 0.3 |
| **TOTALS** | **541,681** | **50,848** | **86.1** | **57,250** | **4,414** | **7.5** | **59,272** | **2,890** | **4.9** | **18,433** | **727** | **1.2** | **668** | **29** | **0.05** | **1,262** | **148** | **0.3** |

**EAST MIDLANDS TOTAL GREENHOUSE GAS EMISSIONS: 59,058 kt $CO_2$ equivalent**

**Table 28 UK and East Midlands Greenhouse Gas Emissions by source (1997) – Detailed Table (Part I)**

| | Carbon Dioxide (kt carbon) | | | Methane (kt) | | | Nitrous Oxide (t) | | | HFCs (t) | | | PFCs (t) | | | $SF_6$ (t) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Emission Source** | **UK** | **EM** | **% of EM** | **UK** | **EM** | **% of EM** | **UK** | **EM** | **% of EM** | **UK** | **EM** | **% of EM** | **UK** | **EM** | **% of EM** | **UK** | **EM** | **% of EM** |
| COMBUSTION IN ENERGY PRODUCTION AND TRANSFORMATION | | | | | | | | | | | | | | | | | | |
| Power stations | 39,678.2 | 7,314.9 | 52.7 | 15.8 | 2.9 | 1.4 | 6000 | 1106 | 11.9 | | | | | | | | | |
| Refineries | 5,820.9 | 0.0 | 0.0 | 0.8 | 0.0 | 0.0 | 300 | 0 | 0.0 | | | | | | | | | |
| Other combustion in energy production and transformation | 5,195.6 | 366.0 | 2.6 | 3.6 | 0.3 | 0.1 | 200 | 14 | 0.2 | | | | | | | | | |
| COMBUSTION IN COMMERCIAL, INSTITUTIONAL, RESIDENTIAL AND AGRICULTURE | | | | | | | | | | | | | | | | | | |
| Domestic combustion | 22,825.3 | 1,622.6 | 11.7 | 34.8 | 2.5 | 1.2 | 600 | 43 | 0.5 | | | | | | | | | |
| Commercial, public & agricultural combustion | 8,818.6 | 621.1 | 4.5 | 4.6 | 0.3 | 0.2 | 200 | 14 | 0.2 | | | | | | | | | |
| COMBUSTION IN INDUSTRY | | | | | | | | | | | | | | | | | | |
| Iron & steel industry combustion | 6,913.1 | 0.0 | 0.0 | 7.9 | 0.0 | 0.0 | 300 | 0 | 0.0 | | | | | | | | | |
| Other industrial combustion | 17,012.3 | 1,120.2 | 8.1 | 3.8 | 0.3 | 0.1 | 1200 | 79 | 0.8 | | | | | | | | | |
| PRODUCTION PROCESSES | | | | | | | | | | | | | | | | | | |
| Industry production processes | 3,310.5 | 218.0 | 1.6 | 8.8 | 0.6 | 0.3 | 69300 | 0 | 0.0 | | | | | | | | | |
| EXTRACTION/ DISTRIBUTION OF FOSSIL FUELS | | | | | | | | | | | | | | | | | | |
| Coal mines | | | | 318.4 | 64.2 | 30.6 | | | | | | | | | | | | |
| Gas leakage | | | | 347.6 | 24.5 | 11.6 | | | | | | | | | | | | |
| Offshore oil and gas | 170.6 | 12.0 | 0.1 | 70.9 | 5.0 | 2.4 | | | | | | | | | | | | |
| ROAD TRANSPORT | | | | | | | | | | | | | | | | | | |
| Road transport combustion | 31,729.1 | 2,243.3 | 16.2 | 20.6 | 1.5 | 0.7 | 10800 | 764 | 8.2 | | | | | | | | | |
| OTHER TRANSPORT AND MOBILE MACHINERY | | | | | | | | | | | | | | | | | | |
| Other transport & mobile machinery: All sources | | | | 2.3 | 0.2 | 0.1 | 3000 | 211 | 2.3 | | | | | | | | | |

## (Part II)

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Off-road sources | 1,500.2 | 105.7 | 0.8 | | | | | | | | | | | | | | | |
| Military | 809.1 | 57.0 | 0.4 | | | | | | | | | | | | | | | |
| Railways | 403.6 | 28.4 | 0.2 | | | | | | | | | | | | | | | |
| Shipping | 994.0 | 4.6 | 0.0 | | | | | | | | | | | | | | | |
| Civil aircraft | 637.1 | 18.4 | 0.1 | | | | | | | | | | | | | | | |
| WASTE TREATMENT & DISPOSAL | | | | | | | | | | | | | | | | | | |
| Landfill | | | | 826.0 | 53.8 | 25.6 | | | | | | | | | | | | |
| Other waste treatment & disposal | 1,545.9 | 108.9 | 0.8 | 56.7 | 4.0 | 1.9 | 500 | 35 | 0.4 | | | | | | | | | |
| AGRICULTURE, FORESTRY & LAND USE CHANGE | | | | | | | | | | | | | | | | | | |
| Enteric fermentation | | | | 892.9 | 44.7 | 21.3 | | | | | | | | | | | | |
| Animal wastes | | | | 110.7 | 5.5 | 2.6 | 5000 | 250 | 2.7 | | | | | | | | | |
| Non-livestock agriculture | 367.1 | 26.6 | 0.2 | 0.0 | 0.0 | 0.0 | 93800 | 6807 | 73.0 | | | | | | | | | |
| OTHER INDUSTRIAL SOURCES | | | | | | | | | | | | | | | | | | |
| Halocarbon production | | | | | | | | | | 1350 | 0.0 | 0.0 | 1 | 0.0 | 0.0 | | | |
| Fire-fighting | | | | | | | | | | 3 | 0.2 | 0.2 | 0 | 0.0 | 0.0 | | | |
| Electronics | | | | | | | | | | 0 | 0.0 | 0.0 | | | | | | |
| Foams | | | | | | | | | | 18 | 1.3 | 1.0 | | | | | | |
| Refrigeration | | | | | | | | | | 861 | 60.6 | 50.1 | 3 | 0.2 | 5.0 | | | |
| Aerosols (including metered dose inhalers) | | | | | | | | | | 835 | 58.8 | 48.6 | | | | | | |
| Aluminum production | | | | | | | | | | | | | 35 | 0.0 | 0.0 | | | |
| Electronics and training shoes | | | | | | | | | | | | | 57 | 4.0 | 95.0 | | | |
| Magnesium manufacture | | | | | | | | | | | | | | | | 30.0 | 4.6 | 74.1 |
| Electrical insulation, electronics and trainers | | | | | | | | | | | | | | | | 22.8 | 1.6 | 25.9 |
| **TOTALS** | **147,731.2** | **13,867.8** | **100.0** | **2,726.2** | **210.2** | **100.0** | **191,200** | **9,323.6** | **100.0** | **3,067** | **121** | **100.0** | **96** | **4** | **100.0** | **53** | **6** | **100.0** |

Emissions of carbon dioxide are given in tonnes of carbon, and emissions of other gases are given in tonnes of each gas

**Table 29 East Midlands Greenhouse Gas Emissions by source (1997) (kt $CO_2$ equivalent) – Detailed Table (Part I)**

| | Carbon Dioxide | | Methane | | Nitrous Oxide | | HFCs | | PFCs | | $SF_6$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Emission Source** | **EM** | **% of EM** | **EM** | **% of EM** | **EM** | **% of EM** | **EM** | **% of EM** | **EM** | **% of EM** | **EM** | **% of EM** |
| COMBUSTION IN ENERGY PRODUCTION AND TRANSFORMATION | | | | | | | | | | | | |
| Power stations | 26821 | 52.7 | 61 | 1.4 | 343 | 11.9 | | | | | | |
| Refineries | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | | | | | | |
| Other combustion in energy production and transformation | 1342 | 2.6 | 5 | 0.1 | 4 | 0.2 | | | | | | |
| COMBUSTION IN COMMERCIAL, INSTITUTIONAL, RESIDENTIAL AND AGRICULTURE | | | | | | | | | | | | |
| Domestic combustion | 5950 | 11.7 | 52 | 1.2 | 13 | 0.5 | | | | | | |
| Commercial, public & agricultural combustion | 2278 | 4.5 | 7 | 0.2 | 4 | 0.2 | | | | | | |
| COMBUSTION IN INDUSTRY | | | | | | | | | | | | |
| Iron & steel industry combustion | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | | | | | | |
| Other industrial combustion | 4108 | 8.1 | 5 | 0.1 | 24 | 0.8 | | | | | | |
| PRODUCTION PROCESSES | | | | | | | | | | | | |
| Industry production processes | 799 | 1.6 | 12 | 0.3 | 0 | 0.0 | | | | | | |
| EXTRACTION/ DISTRIBUTION OF FOSSIL FUELS | | | | | | | | | | | | |
| Coal mines | | | 1349 | 30.6 | | | | | | | | |
| Gas leakage | | | 514 | 11.6 | | | | | | | | |
| Offshore oil and gas | 44 | 0.1 | 105 | 2.4 | | | | | | | | |
| ROAD TRANSPORT | | | | | | | | | | | | |
| Road transport combustion | 8226 | 16.2 | 31 | 0.7 | 237 | 8.2 | | | | | | |
| OTHER TRANSPORT AND MOBILE MACHINERY | | | | | | | | | | | | |
| Other transport & mobile machinery: All ources | | | 3 | 0.1 | 66 | 2.3 | | | | | | |

## (Part II)

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Off-road sources | 387 | 0.8 | | | | | | | | | | |
| Military | 209 | 0.4 | | | | | | | | | | |
| Railways | 104 | 0.2 | | | | | | | | | | |
| Shipping | 17 | 0.0 | | | | | | | | | | |
| Civil aircraft | 67 | 0.1 | | | | | | | | | | |
| WASTE TREATMENT & DISPOSAL | | | | | | | | | | | | |
| Landfill | | | 1131 | 25.6 | | | | | | | | |
| Other waste treatment & disposal | 399 | 0.8 | 84 | 1.9 | 11 | 0.4 | | | | | | |
| AGRICULTURE, FORESTRY & LAND USE CHANGE | | | | | | | | | | | | |
| Enteric fermentation | | | 939 | 21.3 | | | | | | | | |
| Animal wastes | | | 116 | 2.6 | 78 | 2.7 | | | | | | |
| Non-livestock agriculture | 98 | 0.2 | 0 | 0.0 | 2110 | 73.0 | | | | | | |
| OTHER INDUSTRIAL SOURCES | | | | | | | | | | | | |
| Halocarbon production | | | | | | | 0 | 0.0 | 0 | 0.0 | | |
| Fire-fighting | | | | | | | 1 | 0.2 | 0 | 0.0 | | |
| Electronics | | | | | | | 0 | 0.0 | | | | |
| Foams | | | | | | | 8 | 1.0 | | | | |
| Refrigeration | | | | | | | 364 | 50.1 | 1 | 5.0 | | |
| Aerosols (including metered dose inhalers) | | | | | | | 353 | 48.6 | | | | |
| Aluminum production | | | | | | | | | 0 | 0.0 | | |
| Electronics and training shoes | | | | | | | | | 28 | 95.0 | | |
| Magnesium manufacture | | | | | | | | | | | 110 | 74.1 |
| Electrical insulation, electronics and trainers | | | | | | | | | | | 38 | 25.9 |
| **TOTALS** | **50,848** | **100.0** | **4,414** | **100.0** | **2,890** | **100.0** | **727** | **100.0** | **29** | **100.0** | **148** | **100.0** |

**EAST MIDLANDS TOTAL 59,058 Kt $CO_2$ equivalent**

### 7.8.1 Combustion in energy production and transformation

The following section gives details of source categories (as in Tables 5 and 6) and data used in determining emissions for each individual greenhouse gas.

Greenhouse gas emissions related to this source category arise from the combustion of fossil fuels in power stations, their use in refineries, and in other energy production and transformation.

**Power stations ($CO_2$, $CH_4$, $N_2O$)**

There are a number of emissions from combustion in electricity generation, including carbon dioxide, methane and nitrous oxide and other greenhouse gases included in the Kyoto agreement, and other gases including nitrogen oxides and sulphur dioxide. Nationally, the decrease in carbon dioxide emissions from power generation in recent years has made a significant contribution to the reduction in the UK's total carbon dioxide emissions, with the mix of fuels used in electricity production having changed (eg reduction in coal use, increase in gas use). However emissions are expected to increase in future years (RCEP, 2000).

Emissions by source rather than by end-user have been considered. Instead of considering the quantity of emissions related to the amount of electricity consumed in the East Midlands Region, available data on emissions related to electricity generation sources located in the Region has been utilised. There is an above average concentration of power generation in the East Midlands compared to other UK regions. Major power stations in the East Midlands are West Burton (coal), High Marnham (coal), Ratcliffe-on-Soar (coal), Willington B (coal), Cottam (coal, and combined cycle gas turbine (from 1999)), Sutton Bridge (combined cycle gas turbine (from 1999)), Corby (combined cycle gas turbine), and Derwent (CHP) (DTI, 1999a).

Power station emissions in the inventory include not only emissions connected with electricity use in the Region but also emissions related to the consumption outside the Region of electricity exported from the Region's power stations. Alternatively, an end-user approach could be used since there is an argument that the end-user is obtaining most of the benefit from the emission generating activity and so is more responsible for it.

Carbon dioxide emissions data for individual East Midlands power stations has been obtained from the Environment Agency (Environment Agency, 2000), National Power 1998 Environmental Performance Review, and the TXU Europe (formerly Eastern Group) internet site. This information has been used to estimate 1997 carbon dioxide emissions for East Midlands power stations. Methane and nitrous oxide emissions associated with power stations have been estimated for 1997 by scaling national emissions data (NETCEN, 1999b) using the ratio of the East Midlands and UK power stations' carbon emissions to obtain an estimate for the Region.

**Refineries ($CO_2$, $CH_4$, $N_2O$)**

Oil refinery operations emit the gases carbon dioxide, methane and nitrous oxide in their day to day work.

There are no refineries in the East Midlands (DTI, 1999b) therefore it is assumed that there are no emissions for this source category.

**Other combustion in energy production and transformation ($CO_2$, $CH_4$, $N_2O$)**

This category includes coke production, solid smokeless fuel production, town gas production, and offshore own gas use.

Only national emissions data has been readily available. As it is difficult to estimate how much of the activities covered by this category are carried out in the East Midlands national emissions data (NETCEN, 1999b) has been scaled to the East Midlands level using the ratio of the regional and national populations (ONS, 1999) (4,156,300 / 59,008,600 = 0.07).

### 7.8.2 Combustion in commercial, institutional, residential and agriculture

This category refers to greenhouse gas emissions from fuel combustion in the domestic, and commercial, public and agricultural sectors.

**Domestic combustion ($CO_2$, $CH_4$, $N_2O$)**

Emissions from the combustion of fuels in the domestic sector are considered in this category.

There has been a significant amount of coal mining activity in the East Midlands. Therefore a large number of houses in mining areas will have coal burning fires and boilers, and there is likely to be an above average use of coal in housing in the Region. Each local authority with a responsibility for housing has produced a report required under the Home Energy Conservation Act, containing information related to energy and local housing. As it was felt that it would be difficult to obtain all the necessary reports for the East Midlands and that it was likely that not all of the information would be in the required form, these reports were not used in this initial inventory. At the East Midlands level the only relevant data that is readily available are gas data for the East Midlands distribution zone of Transco (see DTI, 1999b).

Since there are not complete data for the East Midlands, national emissions data (NETCEN, 1999b) have been scaled using the ratio of the number of households in the East Midlands Region (Spring 1998) and in the UK (ONS, 1999) (1,721,000 / 24,209,000 = 0.071). Two possible scaling factors were considered; number of households, and population. The number of households was considered to be more representative for the regional estimate, although the two scaling factors are actually very similar.

**Commercial, public & agricultural combustion ($CO_2$, $CH_4$, $N_2O$)**

The category refers to emissions from the combustion of fuels in the commercial, public and agricultural sectors.

Energy data is available for public sector buildings, but insufficient data has been available on overall energy use for sectors in this category for the East Midlands. Therefore national emissions data (NETCEN, 1999b) has been scaled using the ratio of the Region's population and national population (ONS, 1999) (0.07) to obtain an estimate of regional emissions.

### 7.8.3 Combustion in industry

This source category is sub-divided into iron and steel industry combustion and other industrial combustion.

**Iron and steel industry combustion ($CO_2$, $CH_4$, $N_2O$)**

Emissions associated with the iron and steel industry are counted in this category.

The Iron and Steel Statistics Bureau (http://www.issb.co.uk) gives the following steel production figures:

East and West Midlands steel production (1997) = 16 kt.

UK steel production (1997) = 18,502 kt.

From this information, it is assumed there is negligible iron and steel production in the East Midlands Region although some is produced by George Fischers.

**Other industrial combustion ($CO_2$, $CH_4$, $N_2O$)**

Carbon dioxide, methane and nitrous oxide emissions from the combustion of fuels for energy in industry are considered in this category.

In the absence of regional energy consumption data which could be used to estimate emissions using emission factors, national emissions data (NETCEN, 1999b) has been scaled to the East Midlands Region. Gross Domestic Product (GDP £million) (ONS, 1999) was considered to be more representative of industrial activity in the Region than population and so was used as the scaling factor (East Midlands GDP £million / UK GDP £million = 45,728 / 694,435 = 0.066). (The GDP scaling factor is actually reasonably similar to that of population.)

### 7.8.4 Production processes

**Industry production processes ($CO_2$, $CH_4$, $N_2O$)**

Emissions associated with production processes in industry are considered, such as cement and lime manufacture, the chemical industry, food and drink processing, and quarrying.

Some emissions information for specific large industrial sites is available from the Environment Agency, for emissions above certain levels and excluding confidential information (Environment Agency, 2000). National emissions data (NETCEN, 1999b) has been scaled by the ratio of regional and national GDP (ONS, 1999) (0.066) to obtain regional estimates.

Nationally a major source of nitrous oxide emissions is the manufacture of adipic acid (used in nylon manufacture) and nitric acid production. As adipic acid and nitric acid production is carried out at one site in North East England (UMIST, 1999), there are no nitrous oxide emissions for this source category in the East Midlands.

### 7.8.5 Extraction/ distribution of fossil fuels

This source category includes methane emissions from coal mines and gas distribution leakage, and carbon dioxide and methane emissions connected with the offshore oil and gas industry.

**Coal mines ($CH_4$)**

Coal mines are a source of methane emissions. Emissions occur from both deep and open cast mines, although emissions per tonne of coal are larger for deep mined coal. Nationally, total methane emissions from coal mines have been following a decreasing trend which has been related to the reduction in the amount of coal produced.

As a relation between coal production and methane emissions has been observed nationally, regional and UK coal production statistics (The Coal Authority) were used in a scaling factor to estimate East Midlands coal mine emissions from national emissions data (NETCEN, 1999b) (9,370,975 t / 46,459,237 t = 0.202). In some coal mines methane emissions are utilised as a fuel. It is assumed that the extent of adoption of this approach in the East Midlands is similar to the UK as a whole.

**Gas leakage ($CH_4$)**

The gas transmission and distribution system is a source of methane emissions. Although these emissions have increased in the past as the amount of gas supplied has increased, recent emissions have been falling as old pipes have been renewed. (NETCEN, 1999a)

Nationally, emissions have been estimated from British Gas information (leakage rates, pipe lengths, etc). Much of the East Midlands is connected to the gas supply system, although some rural parts of the Region are not. In the absence of readily available local data, it was assumed that population (ONS, 1999) was an appropriate scaling factor (0.07) to use with national emissions data (NETCEN, 1999b) to obtain a rough estimate of emissions from gas leakage in the East Midlands. An alternative scaling factor that could have been used would have been households, but this is very similar in size to the population scaling factor and as gas is supplied not only to households but also the non-domestic sector the population factor has been used.

**Offshore oil and gas ($CO_2$, $CH_4$)**

This source category refers to emissions from venting, and well testing, fugitive emissions, and emissions from onshore and offshore loading, associated with the offshore oil and gas industry. Nationally, emissions have been rising as the number of installations has increased but with emission reduction measures by the industry and an anticipated future fall in production it has been considered that future emissions will fall.

As data specific to the East Midlands has not been readily available regional and national population data (ONS, 1999) has been used to scale national emissions data (NETCEN, 1999b) to the East Midlands (factor of 0.07). Details of the percentage of national production related to the East Midlands could provide a more representative scaling factor than population.

### 7.8.6 Road transport

**Road transport combustion ($CO_2$, $CH_4$, $N_2O$)**

This category covers emissions of $CO_2$, $CH_4$, and $N_2O$ associated with petrol and diesel combustion by buses, cars, LGVs, HGVs, and motorcycles. Nationally, greenhouse gas emissions from road transport have been increasing, and are forecast to increase in coming years. Trends include growing car ownership, greater fuel use by passenger and freight transport, greater distance travelled by passenger transport and increased freight travel (DTI, 1999c).

In the absence of regional data, the available emissions data for the UK (NETCEN, 1999b) has been scaled using the pro-rata factor ‘Number of cars licensed’ (ONS, 1999), which it has been assumed is more representative for transport activity than population, to obtain a rough estimate of emissions for the East Midlands (East Midlands cars licensed / UK cars licensed = 1,655,000 / 23,408,000 = 0.071).

There is a large amount of traffic using motorways in the East Midlands Region, with many vehicles from other areas using roads in the Region. No distinction has been made between travel through the East Midlands Region and travel by residents of the East Midlands. Also, the possible impact of travel demand management initiatives in the Region has not been considered in this initial inventory.

### 7.8.7 Other transport and mobile machinery

Greenhouse gas emissions related to fuel use by other transport and mobile machinery, including off-road sources, military, railways, shipping, and civil aircraft, are considered in this source category.

**Other transport and mobile machinery: all sources ($CO_2$, $CH_4$, $N_2O$)**

This category refers to off-road sources, military, railways, shipping and civil aircraft.

The available emissions data (national) (NETCEN, 1999b) has been scaled to the East Midlands level using population (ONS, 1999) (0.07) to obtain an estimate for the Region.

**Off-road sources**

This source category covers mobile equipment run on petrol or diesel, eg industrial, agricultural and gardening equipment, and aircraft support

National emissions data (NETCEN, 1999b) has been scaled using a population ratio (0.07) (ONS, 1999) to give an estimate for the Region.

**Military**

This covers fuel used by military aircraft and naval vessels.

National emissions data (NETCEN, 1999b) has been scaled using a population ratio (ONS, 1999) (0.07) to give an estimate for the Region.

**Railways**

National emissions data (NETCEN, 1999b) has been scaled using a population ratio (ONS, 1999) (0.07) to give an estimate for the Region.

Railtrack produce a greenhouse gas emissions inventory.

**Shipping**

The category refers to fishing and coastal shipping.

Movement of shipping cargo (DETR 1999a) has been used as a pro rata factor to scale National emissions data (NETCEN, 1999b) to the East Midlands Region. (East Midlands shipping cargo (Mt)/UK shipping cargo (Mt) = 2.5/538.9 = 0.005)

**Civil aircraft**

This refers to air transport emissions below 1km of take off and landing. Nationally, the amount of air travel carried out has been increasing.

Aircraft movements (aircraft landings or take offs) data (DETR, 1999a) for the UK (all operators - UK and foreign) and for East Midlands airport has been available and so has been used to obtain a scaling factor to estimate East Midlands emissions from national emissions data (NETCEN, 1999b). (East Midlands aircraft movements/UK aircraft movements = 41,000/1,423,000 = 0.029) Air transport is more representative than population for the regional estimate.

### 7.8.8 Waste treatment and disposal

This category covers methane emissions from landfill, and also greenhouse gas emissions from other waste treatment and disposal.

**Landfill ($CH_4$)**

Methane emissions arise from biodegradable waste in landfill sites. Emissions have been falling, largely because of the increased recovery of methane at landfill sites.

The available national emissions data (NETCEN, 1999b) has been scaled to the East Midlands level using as a pro-rata factor, quantity of waste deposited in landfills (East Midlands data from Environment Agency Strategic Waste Management Survey, UK data from Environment Agency website, State of the Environment 'The Management of Wastes'). (East Midlands quantity of waste deposited in landfills (tonnes) / UK quantity of waste deposited in landfills (tonnes) = 8,864,000 / 136,000,000 = 0.065). It has been assumed that the extent of methane recovery from landfills in the East Midlands is similar to the UK average. It is considered that the material deposited factor may be more representative than population for the regional estimate.

**Other waste treatment & disposal ($CO_2$, $CH_4$, $N_2O$)**

Emission sources in this category include sewage treatment and waste incineration and offshore flaring of gas.

National emissions data (NETCEN, 1999b) has been scaled using the population scaling factor (0.07) (ONS, 1999) to give an estimate for the Region.

### 7.8.9 Agriculture, forestry and land use change

Emissions of greenhouse gases from enteric fermentation, animal wastes, and non-livestock agriculture are included in this source category.

**Enteric fermentation ($CH_4$)**

This category refers to methane emissions from enteric fermentation in livestock (eg cattle, sheep, and pigs, with dairy cattle being the main source). Nationally, the quantity of these emissions has been falling, which has been associated with a decrease in the numbers of dairy cattle and improved cattle productivity (National Atmospheric Emissions Inventory 1997 Report).

Data on national emissions from this source (NETCEN, 1999b) has been available. This data has been scaled by a pro-rata factor to give estimates for the Region. Agricultural livestock population (cattle and calves) (ONS, 1999) has been selected for use as a scaling factor as it is considered to be more representative than population for a regional estimate. (East Midlands agricultural livestock population (cattle and calves) / UK agricultural livestock population (cattle and calves) = 577,000 / 11,519,000 = 0.05)

**Animal wastes ($CH_4$, $N_2O$)**

The category refers to emissions of methane and nitrous oxide from animal wastes (eg cattle, pigs, poultry, and sheep).

National emissions data (NETCEN, 1999b) has been scaled to the East Midlands using agricultural livestock population (cattle and calves) (June 1998) (ONS, 1999) as a pro-rata factor (0.05). This factor is more representative than population.

**Non-livestock agriculture ($N_2O$, $CO_2$)**

Non-livestock agriculture covers nitrous oxide emissions arising mainly from soils from fertiliser use, nitrate leaching and run off. Other sources include atmospheric deposition of NOx and ammonia. Carbon dioxide emissions considered in this category are those associated with land use change and forestry (emissions from soil as a result of liming).

National emissions data (NETCEN, 1999b) has been scaled using a pro-rata factor (total area on agricultural holdings (June 1997)) (ONS, 1999) to obtain regional estimates. (East Midlands total area on agricultural holdings (hectares) / UK total area on agricultural holdings (hectares) = 1,231,000 / 16,963,000 = 0.073). Since this category refers to non-livestock agriculture, a factor relating to crop area rather than animal population is more representative for the Region.

### 7.8.10 Other industrial sources

**Hydrofluorocarbons sources (HFCs) (halocarbon production, fire-fighting, electronics, foams, refrigeration, aerosols)**

HFC emissions associated with halocarbon production in the UK have been mainly HFC 23 emissions from HCFC 22 manufacture which takes place at two UK sites (Runcorn and Bristol) (UMIST, 1999). Recent improvements have significantly reduced these emissions (DETR, 2000). Smaller amounts of HFC from HFC manufacture in the UK is only carried out by ICI (DETR 1999b). It is assumed that there is no halocarbon manufacture in the East Midlands. Other HFC emissions sources include fire-fighting fluids, foams (manufacture, and leakage, associated with foam blowing), refrigeration (manufacture, leakage, and disposal of refrigerants used in refrigeration/air conditioning), general aerosols and metered dose inhalers, and solvents. Nationally, it is anticipated that future HFC emissions from these sources will rise.

Data on HFC emissions by source is available for the UK (NETCEN, 1999a). At the regional level, some information is available from the Environment Agency from its inventory of emissions from large industrial sites. National emissions data has been scaled to the East Midlands using the ratio of regional and national population (ONS, 1999) (0.07), where appropriate, to obtain estimates for the Region.

**Perfluorocarbons (PFCs) sources (fire-fighting, aluminium production, halocarbon production, refrigeration, electronics and training shoes)**

PFC emission sources include the electronics industry, aluminium smelting, refrigeration/air conditioning, and fire-fighting. It is assumed there is no aluminium production in the East Midlands. Nationally, future PFC emissions are projected to decrease, largely as a result in reductions in emissions related to aluminium production and the electronics industry, eg through process improvements and increased aluminium recycling (DETR, 1999b).

Data on PFC emissions by source is available for the UK (NETCEN, 1999a). Also, the Environment Agency has information on PFC emissions from large industrial sites. National emissions data has been scaled to the East Midlands using the ratio of regional and national population (ONS, 1999) (0.07).

**Sulphur hexafluoride ($SF_6$) sources (magnesium manufacture, electrical insulation, electronics and training shoes)**

Sources of sulphur hexafluoride emissions include magnesium smelting where it is used as a cover gas, electrical insulation (eg for high voltage electrical switchgear), electronics and trainers (cushioning in sole of shoes). Nationally, future emissions associated with magnesium smelting and electrical insulation are projected to rise while overall emissions remain about the same.

Data on sulphur hexafluoride emissions by source is available for the UK. The Environment Agency's inventory of emissions from large industrial sites is able to provide information on local emission sources. An industrial firm in the Region has provided information on its emissions. For other sources, national emissions data (NETCEN, 1999a) has been scaled to the East Midlands using the ratio of regional and national population (0.07) (ONS, 1999).

## 7.9 East Midlands initiatives to reduce greenhouse gas emissions

The Region has already taken substantial action to reduce greenhouse gas emissions from energy use. Indeed the Region could be considered to be one of the leading Regions in England in terms of the implementation of energy efficiency and renewable energy measures. There is a commitment in the draft Regional Planning Guidance to work towards a target capacity of 400MW of renewable energy by 2005, $CO_2$ reduction strategies are being implemented in several local authorities and the Region has a high concentration of low energy homes. However, most of these initiatives are on a small scale and further investment is needed to help stabilise greenhouse gas emissions by ensuring that these exemplars are replicated throughout the Region.

The following is a list of some of the local initiatives in the Region that are currently reducing greenhouse gas emissions:

- The Region's Universities are active in research to reduce the threat of climate change, with groups at De Montfort University, Nottingham University, Nottingham Trent and Loughborough University researching and teaching energy efficiency and renewable energy;
- There are two European Energy Agencies (Leicester and Newark and Sherwood) and Local Energy Advice Centres in the Region that are helping households and businesses reduce their greenhouse gas emissions;
- In 1993 De Montfort University's Queens' Building was the first low energy, naturally ventilated building winning green building of the year in 1995;
- Newark and Sherwood District's 6,800 Council dwellings has had a rolling programme of energy efficiency improvements since 1988 to reduce low income fuel bills, improve warmth and health of householders. Since 1990 this programme had delivered 20% $CO_2$ emission by 1999;
- In 1994 the UK's first autonomous 'net zero $CO_2$ emission' urban house was built in Southwell;
- In 1998 The UK's first hamlet of 5 terraced autonomous houses to 'net zero $CO_2$ emission' standards were built at Hockerton;
- 1999/2000 probably the largest 'speculative-for-sale' sustainable housing development in the UK at Millennium Green Collingham of 24 dwellings and associated local business centre, with 70% $CO_2$ emission saving to Building Regulation standards;

- Further low energy sustainable housing developments are planned on a larger scale such as 80 dwellings in Ollerton, 100 dwellings in Coddington North Newark, and 3,000 dwellings at Ashton Green in Leicester;
- Establishment of the Midlands Renewable Energy Technology Transfer initiative, a partnership between universities, the public sector and the private sector, to promote renewable energy technology and to help create renewable energy industry in the East Midlands;
- Initiatives in the Region have been looking at the use of alternatively fuelled vehicles. For example the Nottinghamshire Millennium Electric Vehicles Project, a partnership between Nottinghamshire County Council, Nottingham City Council, PowerGen, and the Energy Saving Trust's Powershift programme, intends to promote alternatively fuelled vehicles through the use of a number of electric vans and cars by the County Council, and other organisations. Leicester City Council has been developing an Electric Energy Advice Bus for use in Leicester;
- Boughton Pumping Station in Boughton, Nottinghamshire has been converted into 3,500m$^2$ of workshops, offices, conference facilities with exhibitions. This includes a Renewable Energy display 'Energise 21' linked to a micro 75kW biomass fuelled combined heat and power – this provides the opportunity for the building to be 'net zero $CO_2$ emission' standard;
- Comprehensive monitoring of Leicester's progress towards its 50% $CO_2$ emissions reduction target by 2025 has been underway. Progress has been made as a result of energy efficiency initiatives in Leicester, particularly for housing. Owing to initial difficulties interesting businesses in energy efficiency activities, alternative approaches have been developed;
- Newark and Sherwood's Local Plan 1997 included provision for a biomass power plant in Ollerton on what is now Sherwood Energy Village. A Wind Policy Supplementary Planning Guidance' was issued in 1999. The Newark and Sherwood District Energy Agency's 'Renewable Energy Balance Plan' schedules local renewable energy investments that are practical and necessary to deliver 13% renewable electricity by 2010;
- A variety of renewable energy schemes have been developed in the region, including hydroelectric schemes (eg Beeston Weir near Nottingham), windpower (eg near Loughborough, and at the Hockerton Housing Project), recovery of methane gas from landfill and its use for energy (eg Enderby Warren), obtaining energy from biogas from sewage waste (eg Wanlip near Leicester), waste incineration (Eastcroft incinerator, Nottingham), passive solar (eg Inland Revenue building, Nottingham);
- Beacon Energy, demonstrating the practical case of different types of renewable energy;
- Energy Sense consortium in Leicestershire, Rutland and Northamptonshire, promoting and implementing energy efficiency in housing;
- Nottinghamshire and Derbyshire Local Authorities Energy partnership promoting and implementing energy efficiency and renewable energy;
- Nottingham Energy Partnership, promoting energy services in Nottingham;
- Wilson Millennium Homes at Nottingham University;

- Oadby and Wigston Council have developed a low energy visitor Centre (with the UK's first ventilated photovoltaic array) which will promote renewable energy to schools;
- The Eco House in Leicester has been demonstrating practical energy efficiency and renewable energy measures for over ten years;
- Sherwood Energy Village – a unique initiative to transform a 91 acre former colliery in Ollerton, Nottinghamshire into an environmental enterprise comprising industry, housing, education, recreation and leisure. The on-site developments will comply to the highest environmental standards and a biomass power plant will provide heat and power to the Energy Village and surrounding area. Sherwood Energy Village aim to be a net zero $CO_2$ emission autonomous enterprise;
- Ashton Green, a new community of 3,000 homes designed to maximise renewable energy, energy efficiency and promote sustainable development;
- Local Authorities in the Region have a long record of energy efficiency investment in municipal buildings, schools and housing;
- Local Authorities in the Region are working in partnership with bus companies, rail companies to implement transport demand management strategies. Encouraging people to use alternative modes of transport to the private motor vehicle; and
- The Regional Assembly's "Viewpoints on sustainable energy".

## 7.10 Future activities and opportunities

There will be substantial business opportunities in identifying and implementing energy efficiency and renewable energy measures. The Region has a reputation for carrying out innovative initiatives to reduce greenhouse gas emissions, most notably in the areas of energy efficiency, construction and renewable energy. However more work needs to be done and the Region should set itself tough targets for reducing the gases that cause climate change. The Royal Commission on Environmental Pollution recently suggested a target of a 60% reduction in present $CO_2$ emissions by about 2050 (RCEP, 2000). This is in comparison to the Government target of 20% reduction in $CO_2$ emissions below 1990 levels by 2010.

## 7.11 Conclusions and recommendations

### 7.11.1 Conclusions

An inventory of the estimated greenhouse gas emissions for the six gases included in the UN Kyoto Conference Agreement has been prepared for the East Midlands. Because of the absence of readily available data on actual emissions from the East Midlands Region, it has not been possible to calculate the emissions from "bottom up", with the exception of power station carbon dioxide emissions for example. National emissions data has been apportioned to the East Midlands Region using appropriate scaling factors.

It is estimated that the emissions of the six greenhouse gases amounted to approximately 60 million tonnes of carbon dioxide equivalent, in 1997. Carbon dioxide emissions formed the largest share of this inventory (86%) with methane and nitrous oxide emissions contributing approximately 7% and 5% respectively. The other gases contributed less than 2% of the total emissions. Of the emissions of carbon dioxide, it is estimated that about 53% are due to the combustion of fossil fuels in power stations, 16% are related to the use of fossil fuels in road transport, about 12% from burning fuels in the domestic sector, 8% from fuel combustion in industry, and 4% due to the direct burning of fossil fuels in the commercial, public and agricultural sectors.

It is estimated that almost 90% of the Region's greenhouse gas emissions are related to the use of fossil fuels for energy. Therefore reducing fossil fuel use through increased energy efficiency and increased use of renewable energy is likely to be the most effective way of reducing greenhouse gas emissions. The Regional Assembly's 'Sustainable Energy Strategy' should greatly assist this process.

### 7.11.2 Recommendations

The major difficulty in compiling the greenhouse gas emissions inventory was lack of data. However, data is publicly available at the national level and this national level data is derived from regional data, held by the utilities. At present the utilities are unable to provide energy-related greenhouse gas emissions data on a regional basis.

In order for the Region to effectively monitor its progress towards reducing greenhouse gas emissions, it needs local data. The utilities should therefore be encouraged to provide such data (preferably on a postcode basis), for example to the Regional Observatory. The Regional Observatory could then monitor the Region's progress towards any future greenhouse gas emissions reduction targets.

Some data does exist at the regional level. The Environment Agency maintain an inventory of emissions from large industrial premises in England and Wales and this data has been used in compiling this inventory of greenhouse gas emissions in the East Midlands. In addition, local authorities in the Region have to produce Home Energy Conservation Act reports. These reports should identify the energy consumption from the domestic sector in each Energy Conservation Authority. However, owing to the large number of local authorities in the Region and as it is anticipated that different local authorities take slightly different approaches these figures have not been collected to give a regional overview.

There is therefore a need for a clear common basis on which to calculate regional greenhouse gas emissions from housing and, again, this will be related to a lack of information from utilities on domestic energy consumption. There is a similar lack of readily available information for the business and transport sectors, so agreement on an approach to estimating emissions in these sectors is needed.

Once an acceptable method of determining greenhouse gas emissions has been established and these emissions are being monitored on a regular basis, then the progress towards the East Midlands targets can be measured. The Region's progress will be dependent upon the speed at which it implements large scale measures to both improve energy efficiency and increase the proportion of renewable energy within the Region. The first step towards achieving this is integrating energy efficiency and renewable energy into the Region's policies. The new Regional Planning Guidance makes the first step by setting a target of 400 MW of renewable energy by 2005 as well as encouraging development to energy efficiency standards in excess of current building regulations. Since the DETR guidance on low energy communities was developed in the Region (General Information Report 53) the Region should be in a key position to adopt this standard for all developments in the future.

The key to the Region's success in achieving its greenhouse gas emissions reductions targets will be:

- How effectively it integrates energy efficiency and renewable energy into existing policies at the regional and local level; and
- How effectively the Region is able to work in partnership with the public and private sectors to implement such measures in new and existing buildings and industry and create new employment opportunities in the growing field of energy efficiency and renewable energy technologies.

## 7.12 References

DETR (1999a), Transport Statistics Great Britain, 1999 Edition, The Stationery Office, London.

DTI (1999b), Digest of UK Energy Statistics 1999, The Stationery Office, London.

Environment Agency (2000), Personal communication.

Environment Agency, State of the Environment 'The Management of Wastes', Environment Agency website (http://www.environment-agency.gov.uk/s-enviro/stresses/5waste-arisings/2disposal/5-2.html)

Environment Agency, Strategic Waste Management Survey, East Midlands Environment Agency.

Iron and Steel Statistics Bureau, Iron and Steel Statistics Bureau website (http://www.issb.co.uk).

National Power, 1998 Environmental Performance Review (http://www.national-power.com/environment98/data.htm)

NETCEN (1999a), National Atmospheric Emissions Inventory 1997 Report (http://www.aeat.co.uk/netcen/airqual/naei/annreport/naei97.html).

NETCEN (1999b), UK National Air Quality Information Archive – Statistics Database Atmospheric Emissions Summary Statistics (http://www.aeat.co.uk/netcen/airqual/index.html).

Office for National Statistics (1999), Regional Trends 34, 1999, Office for National Statistics, The Stationery Office, London.

The Coal Authority, The Coal Authority Production and Manpower Returns for 12 month period ending December 1997, The Coal Authority website (http://www.coal.gov.uk/departments/licensing/ProductionAndManpowerReturns/12mth97.htm).

TXU Europe Power, TXU Europe Power website (http://www.easterngeneration.co.uk/mg_frame.htm)

**Other background sources:**

BIFFA (1997), Great Britain plc. The environmental balance sheet, Biffa Waste Services.

DETR (1998), Digest of Environmental Statistics No 20, 1998.

DETR (1999), Environmental Reporting: guidelines for company reporting on greenhouse gas emissions.

DETR (1999b), UK Emissions of HFCs, PFCs and $SF_6$ and Potential Emission Reduction Options, January 1999.

DETR (2000), Climate Change. Draft UK Programme, DETR, London.

DTI (1999a), The Energy Report 1999, The Stationery Office, London.

DTI (1999c), UK Energy Sector Indicators 1999, DTI, London.

Environment Agency, East Midlands Regional Local Government Association, RSPB, Government Office For The East Midlands (1999), Sustainable development indicators. Monitoring Change in the East Midlands.

Environment Agency, The Countryside Agency, East Midlands Regional Local Government Association, Government Office For The East Midlands (1999), Viewpoints on the East Midlands Environment.

Land Use Consultants/ETSU (1996), East Midlands Renewable Energy Planning Study. Final Report, March 1996, London.

Leicester City Council (1994), Development of Information Systems and Computer Models for Improving Energy Management in the Urban Environment, Leicester, Leicester City Council.

Leicester City Council (1994), The Leicester Energy Strategy, Leicester, Leicester City Council.

Leicester City Council (1996), Home Energy Conservation Act Report (HECA), Leicester, Leicester City Council Housing Department.

Leicestershire County Council/De Montfort University (1995), Identification and Utilisation of Energy Resources to Minimise the Effect on the Environment in Leicestershire (UK), Leicestershire County Council/De Montfort University.

Lindley S.J., Longhurst J.W.S., Watson A.F.R and Conlan D.F. (1996), Procedures for the Estimation of Regional Scale Atmospheric Emissions – An Example from the North West Region of England, Atmospheric Environment, Vol. 30, No 17, pp. 3079-3091.

Newark and Sherwood Energy Agency (1998), An Energy Strategy for Newark and Sherwood Energy Agency 1997 to 2010, February 1998.

RCEP (2000), Energy – The Changing Climate. Summary of the Royal Commission on Environmental Pollution's Report, London, The Royal Commission on Environmental Pollution.

UMIST (1999), Fuelling the Warming. A First Attempt at Producing an Inventory of Greenhouse Gas Emissions for the North West of England, December 1999, UMIST, ARIC, North West Climate Group.

# 8. What are the Key Strategic Processes in the East Midlands that should be Considering the Potential Impacts of Climate Change?

*Main Author: Jim Kersey, Entec*

The implications of climate change will need to be built into a wide range of decision makinmg processes. There are a number of strategic processes in the East Midlands that should be considering the potential impacts of climate change. This study can help to inform the development of strategies, plans and policies. Further studies are being commissioned at the national level that will also be helpful in informing strategic processes. These include studies coordinated by UKCIP such as one on the potential health impacts of climate change being carried out for the Department of Health and the work to be commissioned by the Department of the Environment, Transport and the Regions on the implications for planning of climate change.

In the Region the most wide-ranging strategic process is the Integrated Regional Strategy (IRS) being coordinated by the Regional Assembly. The Regional Assembly has created the IRS Policy Forum to develop the IRS. It consists of local government elected Members, representatives from the voluntary sector, East Midlands Development Agency (emda), Government Office of the East Midlands (GO-EM), trade unions and the education, health, business and environment sectors.

The IRS has four principle purposes. These include the following aims:

- Provide a framework for sustainable development;
- Strengthen regional partnership working;
- Integration of regional policies and strategies; and
- Maximise influence for the Region with national Government, the European union and other bodies.

The achievement of all these aims will be necessary if climate change is to be fully integrated into the strategies for the Region.

The IRS process includes developing a series of documents that describe various aspects of the Region. These include those covering the environment, economy, culture, health, spatial issues, social inclusion, housing, rural development, crime, energy, skills and learning and human resources. Some of these have been done, others are in development and others are planned for the future. These documents will be used to inform the production of a number of strategies. Some are already being produced eg the regional economic development strategy "Prosperity through People", consultation draft regional planning guidance for the spatial development of the East Midlands and an interim regional transport strategy. Other strategies are under development including those covering housing, culture, learning and skills, the environment and energy. Others are planned for the future including ones covering crime, human resources, health and skills and learning.

The processes described above makes the IRS a good starting point for climate change to be considered and then guidance given to the other strategies. The draft RPG and economic development strategy have been subject to a sustainability appraisal that included consideration of climate change impacts and emissions. They already contain some climate change related policies such as a target for 400MW of renewable energy for the Region by 2005.

The present study can be used to inform the IRS process at the strategic level and hence gain maximum influence. At a more detailed level, various organisations within the Region could use the study to inform their strategic planning processes such as developers, water companies and the Environment Agency. The latter could use the study to inform the development of their Local Environment Agency Plans (LEAPs). An analysis of the issues that could be affected by climate change in the Region's LEAPs is contained in Chapter 3.

# 9. Recommendations

*Main Author: Jim Kersey, Entec*

## 9.1 Indicators of Climate Change

In order to monitor to what extent climate change continues to happen and its consequences, a number of parameters should be monitored. Indicators of climate change can cover:

- Continuing measurements of climate variables such as rainfall and temperatures. These measurement will identify whether climate change is happening. Presence of certain plant or animal species in the Region could also indicate the extent of climate change;
- Assessment of climate change impacts such as changes in agricultural practice, distribution of flora and fauna, river flows; storms and sea level changes. These assessment help in planning adaptations to climate change; and
- Emissions of greenhouse gases. This will help in setting targets for reducing greenhouse gas reductions.

### 9.1.1 Climate Variables

Records on temperature and rainfall exist in the Region (see Chapter 4) and should be monitored and analysed to identify changes in climate variables.

### 9.1.2 Climate Change Impacts

Some climate change impacts are measured by statutory agencies such as the Environment Agency, whilst data on others are collected more informally such as that on species distribution and behaviour. Water companies collect data on the availability of water resources, which is an indicator of changes in climate. Other organisations such as MAFF collect data on agricultural practices.

### 9.1.3 Climate Change Mitigation

At present little data exists on emissions of greenhouse gases in the Region. This is a major barrier to formulating appropriate sectorally based emissions reduction targets. The document "Sustainable Development Indicators – monitoring change in the East Midlands" also observed that energy use expressed as $CO_2$ is a key indicator. The indicator should cover emissions of all greenhouse gases.

DETR has produced a set of indicators for sustainable development "Quality of life counts". The indicators are split into two categories – headline indicators (to present a high level overview of progress and that can be used for communicating the main messages) and detailed indicators (that can be used for more detailed analyses).

The headline indicator that has been proposed for climate change is emissions of greenhouse gases. The reason for using this indicator is to assess progress on reducing our emissions of greenhouses now and to plan for greater reductions in the longer term. Section 9.2 below describes the Government's targets for emissions reductions.

Carbon dioxide emissions fell in the first half of the 1990s due mainly to a switch from coal to gas and nuclear power for electricity generation. Emissions are expected to rise again after 2005. However, larger reductions will be needed in the future to address the risk of climate change. A recent report from the Royal Commission on Environmental Pollution "Energy – the Changing Climate" has suggested that the UK should be adopting a target of reducing $CO_2$ by 60% over the next 50 years. This would be an even greater challenge for the UK and the Region.

The following table is a summary of a table from "Quality of life counts". It lays out the detailed indicators on climate change:

**Table 30 Climate Change Indicators: Objectives and Trends (From "Quality of life counts")**

| **Objective** | Indicator | | Change since 1970 | Change since 1990 |
|---|---|---|---|---|
| Climate change must be kept within limits which global society can accommodate | Rise in global temperature* | | X | X |
| Assess vulnerability to changed weather patterns and high sea levels and develop adaptation strategies | Sea level rise* | | X | X |
| Continue to reduce our emissions of greenhouse gases now and plan for greater reductions in the longer term | Emissions of greenhouse gases (headline indicator) | | ... | ✓ |
| | Carbon dioxide emissions by end user | Transport | X | X |
| | | Non-Transport | ✓ | ✓ |
| In the longer term more energy will have to come from new and renewable sources | Electricity from renewable sources | | ... | ✓ |
| Fossil fuel resources managed in an environmentally acceptable way | Depletion of fossil fuels | | ... | ~ |

* Trends should be viewed as longer term than three decades

Key:

✓ Significant change in direction of meeting objective

x Significant change in direction away from meeting objective

~ no significant change

• • • trend is uncertain or no quantitative data available

Data should be collected for the above areas in order to assess whether climate change is happening in the Region, its impact and the quantity of greenhouse emissions.

A recent study "Indicators of Climate Change in the UK" for DETR suggests a statistical approach to indicators at the national level. Developments following this report should be monitored as it may be appropriate to use these indicators at the regional level.

## 9.2 Emissions Reduction Targets

Targets can be used to help develop focused policies and action programmes and measure progress. There are two types of targets – quantitative and qualitative. Examples of quantitative climate change targets are:

- The Government's commitment to reducing $CO_2$ emissions to 20% below 1990 levels by 2010. From April 2001, business use of energy will be subject to the Climate Change Levy. This will increase the cost of energy from traditional sources. This gives an incentive for businesses to reduce their emissions and use renewable energy sources (as these are not subject to the levy);
- Under the Kyoto Protocol, the Government is also committed to reducing the six major greenhouse gases (see above) by 12.5% compared to 1990 levels over the period 2008-2012; and
- There are also quantitative targets that could be used to help reduce greenhouse gas emissions such as the Government's target to generate 10% of the UK's electricity from renewable energy by 2010 and 5% by the end of 2003. A target could be set for the amount of electricity sales in the Region that are from renewable sources, as it is now possible for large and small consumers to purchase electricity from renewable energy sources.

An example of a qualitative target is the number of businesses and organisations implementing greenhouse gas reduction programmes. In June 1999, DETR produced guidelines for company reporting on greenhouse gas emissions. Organisations could use these guidelines to assess their emissions and then produce a reduction plan.

Most of the above indicators and targets could be used in the Region. However, there are some information gaps, most notably on greenhouse gas emissions. A further study should be carried out to assess the feasibility of collecting the data and implementing both indicators and targets. It may be possible for instance for the Region to have higher targets such as for renewable energy generation and emissions reductions.

## 9.3 Future Research Requirements

The following is a summary of the future research requirements identified throughout the report:

- Regional Local Environment Agency Plans (LEAPs) will need to consider whether and if so, to what extent, climate change impacts could affect the Plan;
- The impacts of climate change on social inequalities eg impacts on poorer rural and inner city areas and changes in employment patterns eg agriculture and tourism;
- The next set of UKCIP climate change scenarios will be published in the autumn of 2001. These scenarios will draw upon revised IPCC emission scenarios as well as the results of new Regional Climate Model experiments. In the meantime, several recommendations

are made with respect to improving existing climate change scenarios for the East Midlands:

- Possible changes in other climate variables (such as wind speed, humidity, evaporation and solar radiation) should be considered alongside temperature and precipitation. These data could be obtained from existing RCM experiments or generated using SDS methods;
- Further work should be undertaken to evaluate possible changes in the distributions of *daily* climate variables. Published work on extreme precipitation events (Osborn et al., 2000), for example, could be augmented by similar studies of wind spectra, flooding or drought duration/severity;
- Dynamically and statistically downscaled climate scenarios should be compared to determine the most appropriate combination of predictor variables to represent both the *present*–day climate and future climate *change* across the East Midlands (as in Murphy, 1999; 2000). This would increase the physical realism of the SDS method (within the constraints imposed by the range of archived GCM variables) and ensure greater consistency between the two approaches; and
- Dynamically and statistically downscaled climate scenarios could be used to drive a range of hydrological and agricultural impact models. This would facilitate assessments of the significance of regional climate change relative to historic climate variability (as in Hulme et al., 1999), as well as the significance of model uncertainty (as in Wilby et al., 1999).

- SevernTrent Water's result from the modelling of climate change impacts on water resources is quite different from that of other water companies (such as North West Water and Anglian Water). The latter have shown a decrease in yields using the UKWIR method under certain scenarios, but an increase in yields for other scenarios. The reasons for this different projection need to be more thoroughly examined as do the disadvantages and benefits of a statistical, as opposed to a more physically-based, modelling approach;
- What level of extra flooding protection should be planned for and implemented;
- Detailed site-specific hydrological and biological modelling would be required to evaluate the impacts of climate change upon wetland habitats in the East Midlands;
- Change in the distribution of rainfall could also have an effect upon coastal amphibians such as the natterjack toad, which have been reintroduced to Gibraltar Point NNR in Lincolnshire;
- A major problem in assessing the impacts of climate change upon cultural heritage is a lack of clear empirical evidence and more research in this area would be helpful;
- Climate sensitive construction companies will need to know how rainfall patterns will change in specific areas in terms of when rain falls and how intensely. These, of course, are issues which climate change science cannot yet answer with any accuracy;
- Businesses will need greater certainty in the projections of climate change before they significantly take forward the issue of responding to climate change impacts. They will find if very difficult to respond on the basis of scenarios which indicate significant differences in the rate of change in climate variables;

- Further detailed and localised research on the potential impacts of climate change including on the tourist industry is likely to be necessary along parts of the Lincolnshire coastline; and
- Ongoing and further montiroing should be carried out on indicators of climate change.

The above represents a significant commitment to begin to understand what climate change could mean in more detail for the Region. This level of detail should give planners the ability to plan more firmly with climate changes in mind.

# 10. Conclusions

*Main Author: Jim Kersey, Entec*

## 10.1 Summary of Regional Climate Change Impacts and Adaptation Options

The following tables summarise the main impacts and some adaptation options for the Region.

### WATER RESOURCES AND QUALITY

| IMPACT | Time scale for Response | | | Adaptation Strategy (example in brackets) |
|---|---|---|---|---|
| | S | M | L | |
| Changes to Water Supply<br><br>Possible reduction in yields of surface water (eg for River Trent and Derwent Valley systems), though some aquifer recharge could benefit (eg Sherwood aquifer). | ■ | | | Demand-side management eg water meters, water conservation and efficiency campaigns. |
| Reduction in water abstraction | ■ | | | Supply-side management: eg leakage reduction, increased pump storage of winter water, farm reservoirs, more water recycling, more regional water transfer schemes (eg West to East Midlands via River Trent). |
| | | | ■ | Long term supply options: eg north west UK to south east UK water transfers; new reservoirs |
| Changes to Water Quality<br><br>Eg through low river flow rates hence less dilution, turbulence from intense rainfall | ■ | | | Enhanced water treatment<br><br>More management of rivers to maintain and control flows |

S = Short-term
M = Medium-term
L = Long-term

## GENERAL FLOODING RISKS: URBAN & LOWLANDS

| IMPACT | Time scale for Response | | | Adaptation Strategy (example in brackets) |
|---|---|---|---|---|
| | S | M | L | |
| Lowland flooding risk | | | | Increase the height of levees (eg Northampton) |
| | | | | Restrict/control over development |
| | | | | Stronger policy framework on appropriate development in flood plains from central government |
| | | | | Adjust planning restriction to only allow development that does not have runoff rates greater than greenfield sites (eg strategic review of development in Northampton) |
| | | | | Use sustainable urban drainage techniques such as settling ponds to intercept flood water (eg Central Rivers Project) and replacing bends in rivers to slow down water (eg Erewash) |
| | | | | Designated floodplain area (eg Trent Floodplain Initiative) |
| Socio-economic impact of flood (insurance claims procedures, costs, psychological impact) | | | | Social and community involvement in response (eg 'Flood Alert' in Northampton) |
| | | | | Pro-active response from Insurance industry |
| Increased pumping costs for land drainage | | | | Potential redesign/retro-fitting of pumping installations for internal drainage to increase capacity |
| Urban & Industrial Waste Water Management | | | | Reed bed settling ponds for purification |
| Foul water flooding | | | | Upgrade the capacity of flood water storage systems |
| | | | | Increase pumping capacity |
| | | | | Increase capacity for waste water treatment |

## AGRICULTURE

| IMPACT | Time scale for Response | | | Adaptation Strategy (example in brackets) |
|---|---|---|---|---|
| | S | M | L | |
| Summer droughts leading to increased irrigation demand from new crops | | | | Install small scale water reservoirs on farmland |
| | | | | More efficient use of water (mechanical and biotechnological)<br>Re-negotiation of water abstraction licences<br>Water charging/tradable permit schemes to promote efficient use of prescribed (reduced) source |
| | | | | Change the perceptions of supermarkets demanding "thirsty" varieties of crop and associated irrigation regimes |
| Difficulty in predicting suitability for planting in Autumn | | | | More flexible approach to planting (French approach) |
| Clay soils difficult to work in wetter conditions | | | | Addition of organic material into soil |
| Heat stress upon livestock | | | | Increase tree cover to provide shade |
| Flooding | | | | Move towards farmers as "custodian" of floodplain lands or of 'carbon sinks' in the uplands with appropriate compensation |
| Soil erosion from flash flooding | | | | Diversification, set aside, reduce grazing pressures |
| Slope failure from excessive rainfall | | | | Advice on adaptation of agricultural practice (contour ploughing ) |
| | | | | Increase woodland and hedgerow area of farmland, which should also increase the amenity value of landscape |
| | | | | Improve plant breeding technology |
| New crop pests eg Colorado Beetle, European Corn Borer | | | | Sustainable integrated pesticides strategy |
| Suitability of conditions for crops to move Northwards | | | | Investment in flexible processing plants for peas, salad crops, etc. such as those that can be easily installed/moved over a period of years |

| IMPACT | Time scale for Response | | | Adaptation Strategy (example in brackets) |
|---|---|---|---|---|
| | S | M | L | |
| Knock-on effect on the supply chain | | | | Increase potential for supplying demand locally/regionally/nationally |
| Potential opportunities for increased food processing and packaging industries | | | | Potential need for new types of agricultural machinery for irrigation, planting and harvesting, etc. |
| Increased potential for biomass crops | | | | Potential benefit for biomass energy crops |

## COASTAL REGION

| IMPACT | Time scale for Response | | | Adaptation Strategy (example in brackets) |
|---|---|---|---|---|
| | S | M | L | |
| Increased sea level, surges, wave heights | | | | Increase sea wall height (eg Skegness) |
| Increased sea wall and cliff erosion | | | | Managed realignment (eg The Wash) |
| | | | | Soft design of sea defences - sand dunes used for defence and beach replenishment (eg LincShore Project) |
| Loss of coastal habitats for wildlife | | | | New habitat creation through realignment of sea defences (eg Lincolnshire Fens) |
| Loss of agricultural land | | | | Managed retreat |
| Damage to buildings and socio-economic losses | | | | Adaptation of buildings to coastal inundation |
| | | | | Potential relocation of existing buildings |
| Tourism opportunities | | | | Market opportunities as season extends throughout the year (eg Skegness, Mablethorpe, etc.) |
| | | | | Need for new infrastructure (sewage, water), and better public transport (eg Ingoldmells caravan site, nr. Skegness) |

## BIODIVERSITY

| IMPACT | Time scale for Response | | | Adaptation Strategy (example in brackets) |
|---|---|---|---|---|
| | S | M | L | |
| Loss of species at edge of southerly distribution (eg Jacobs Ladder in the Peak District) | | | | Habitat corridors (though not always possible for species restricted to specific isolated soils) |
| Increasing species at edge of northern distribution | | | | Management regimes to decrease grazing pressure |
| Incoming southern species (eg Little Egret) | | | | Reduce drainage, reduce water extraction, perhaps even artificial recharge of aquifers (though expensive) |
| Loss of wet and lowland heath species (eg sundew, butterburs in Lincs.) | | | | Maintain (and increase?) sacrificial flooding areas (floodplains) |
| Impact on uplands uncertain: impacts of increased rainfall and increased temperatures unclear on vegetation and on peat formation or deterioration. | | | | Adapt to dynamics instead of preservation per se (eg National Trust). Increase in habitat management investment, 'land banking' (eg Gibraltar Point) |
| Complex interplay of other factors eg winds, visitor pressure, fires etc | | | | Decrease erosion through management of fires (including public education) (eg National Trust, Peak District National Park Authority) |
| | | | | Afforestation with native species to improve habitat |
| Grassland: decreased summer rainfall causes major effects on grasslands, especially on sandy and silty soils | | | | What kind of land management regime can help plants adapt to climate change? |
| | | | | Deliberate microclimate modification by planting trees, hedgerows, artificial lakes, etc. |
| Earlier growth of vegetation: sensitive to late frosts (relatively common in the Region. Bracken very sensitive to late frosts ) <br><br> Knock-on effect on insects and hence birds <br><br> Longer breeding season for certain species | | | | |

## MANUFACTURING, SERVICES AND RETAIL SECTOR

| IMPACT | Time scale for Response | | | Adaptation Strategy (example in brackets) |
|---|---|---|---|---|
| | S | M | L | |
| Limitation on water usage for chemical and food and drinks processing; less efficient cooling from river water | | | | Water efficiency schemes (eg Boots), water recycling<br><br>Tradable water licences; |
| Industrial waste water management systems | | | | As in section on flooding |
| Working and manufacturing conditions more difficult under high temperatures in industry | | | | Installation of air conditioning systems (but will increase energy consumption) |
| | | | | Building design - solar design to make optimum use of solar energy |
| | | | | Retrofitting “natural” ventilation systems<br><br>Adaptation of working patterns – e.g. earlier and/or late in the day (eg Church's Shoes) |
| Food preservation | | | | Better storage facilities, eg more refrigeration but this will increase costs |
| | | | | Transfer of suppliers to reduce transport times & costs |
| Global supply chains | | | | Potential need to adjust sourcing |
| Distribution and production centres at risk from flooding in low lying flat land | | | | Adaptation of flood defences (eg Pedigree). Storage capacity to intercept incoming and outgoing water to reduce flood risk. |
| Increased insurance claims | | | | Strengthening of buildings (esp. roofs), adaptation to flood risk |
| Open shopping areas, more open air retail and social activity | | | | Planning process to factor-in climate change; open outdoor spaces seen as integral to built environment |

## CONSTRUCTION AND BUILDING

| IMPACT | Time scale for Response | | | Adaptation Strategy (example in brackets) |
|---|---|---|---|---|
| | S | M | L | |
| Air conditioning demand increased | ■ | | | Insulation to limit temperature extremes (eg Gusto Construction) |
| | | ■ | | Installation of natural ventilation systems (eg Queens Building, DeMontfort University, Inland Revenue Building, Nottingham) |
| | | ■ | | Urban greening to ameliorate urban microclimatic extremes |
| | | | ■ | Temperature sensitive housing design<br><br>Photovoltaic cells as integral to building design |
| Drought/flooding problems | ■ | | | Increase in size of rain collection tanks (eg Gusto Construction) |
| | | ■ | | Permeable pavements (being tested) |

## TOURISM AND RECREATION

| IMPACT | Time scale for Response | | | Adaptation Strategy (example in brackets) |
|---|---|---|---|---|
| | S | M | L | |
| Increased tourism and hence impacts on biodiversity (disturbance of birds' breeding season) | ■ | | | Restrict timing of visits to nature reserves during critical periods (eg Gibraltar Point) |
| Increased tourism leading to increased transport demand, congestion and pollution extended through year | ■ | | | Sustainable transport initiatives (road closing, charging, cheap frequent, reliable public transport) (eg Peak District) |
| Wetter West and drier East though wetter winters? | ■ | | | All weather facilities (eg Skegness) |
| Angling affected by disturbance to breeding season of fish | ■ | | | Adjustment of angling season |
| Market opportunities but increased tourist pressure on current most popular destinations | | ■ | | Spread of tourism throughout Region (Derwent Valley, Sherwood Forest, Leicestershire Uplands) |

**TRANSPORT**

| IMPACT | Time scale for Response | | | Adaptation Strategy (example in brackets) |
|---|---|---|---|---|
| | S | M | L | |
| Overheating of diesel engines | | | | Adaptation of cooling systems |
| Risk of buckling of railway track | | | | Speed limits - reconfigure track specification for higher temperatures |
| Road surface asphalt melting | | | | Alter asphalt composition |
| Warmer winters - less cold weather disruption but risk of complacency with less frequent snow and ice | | | | Less road grit required – less salt pollution<br><br>Change in winter strategy by road maintenance departments and Railtrack. |
| Aircraft engine efficiency decrease in hot weather | | | | Reduce payloads (eg East Midlands Airport, Rolls Royce) |
| Canals affected by drought | | | | Sharing of lock use by barges, restrictions on summer use |
| Flooding of roads and railways | | | | Improve design and maintenance of infrastructure in risk areas |
| Landslips in uplands from excessive precipitation and overgrazing of pastures | | | | Land management, strengthening of cuttings and embankments |

## 10.2 Concluding Observations

This technical report demonstrates the following:

- The climate of the Region changed during the 20th century;
- The climate of the Region is expected to continue to change in the 21st century due, at least in part, to greenhouse gas emissions from human activities;
- This climate change could have a number of important impacts in the Region such as reduced water resources, increased risk of flooding, changes in agricultural practices, changes in plant and animal species, adverse impacts on infrastructure, increased opportunities for tourism and more outdoor lifestyles;
- The Region will have to adapt to some level of climate change. This will include planning appropriate flood defences, using water resources more efficiently, restricting development in vulnerable areas and adapting living and working conditions;

- Not all the impacts will be negative and there could be considerable opportunities for the Region to develop products and services that help organisations and people to adapt to climate change and also reduce their emissions. Depending on how the Region plans to respond to climate change there could be benefits in some areas including biodiversity, agriculture, renewable energy and commercial and industrial performance improvements;
- A sample of the Region's residents revealed that there is a good level of knowledge and concern about climate change. The respondents were those that had already expressed an interest in environmental issues. The respondents also supported the setting of tough targets for reductions in the Region's greenhouse gas emissions;
- Climate change will also have to be considered alongside other changes affecting the Region from social, economic and environmental trends; and
- The Region should monitor for climate change and set itself tough targets for reducing its greenhouse gas emissions.

# Appendix 1
# Notes from Stakeholders Meetings

25 Pages

# Appendix 2
# Questionnaire on the Impacts of Climate Change in the East Midlands

6 Pages