



Climate change: Assessing the impacts – identifying responses

The first three years of the UK Climate Impacts Programme

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PREFACE

This Report presents the work that has been undertaken in the first three years of the UK Climate Impacts Programme (UKCIP). The Programme was established by the Department of the Environment, Transport and the Regions (DETR) with the aim of establishing a research framework for the integrated assessment of climate change impacts in the UK. Its specific objective is to coordinate and integrate a stakeholder-led assessment of the impacts of climate change at a regional and national level. Assessments under the UKCIP will provide Government and private-sector decision-makers with information needed to underpin the development of strategies to adapt to climate change.

Studies within the Programme fall into two broad groups: sub-UK scoping studies and sectoral studies, which are undertaken in a modular way within a common framework. In the first three years of the Programme five sub-UK assessments studies have been undertaken, four sectoral studies are underway and four further studies are at inception. The results of completed studies are contained in a set of separate Summary and Technical reports for each area¹. In addition, tools to support studies have been developed.

This Report has four purposes:

1. To explain the approaches and methods which have been developed within the Programme, for the benefit of organisations and the research community within the UK and internationally;
2. To enable the next stage of the work of UKCIP to be planned, so that it meets the needs for national policy and supports organisations at a regional and national scale to prepare adaptation responses;
3. To provide a concise synthesis of the results of studies obtained so far and cross-cutting themes emerging, so these can be assimilated in policy-making and strategic planning;
4. To provide a portfolio of future studies for the next phase of the research programme which is needed to achieve a national assessment.

The UKCIP integrating framework is presented in Chapter 1. Results of the sub-UK scoping studies are presented in Chapter 2 and the methodological work underway in the sectoral studies is presented in Chapter 3. This Chapter also contains a review of current sectoral work which is related to the UKCIP framework. In Chapter 4, an attempt is made to integrate and assess study findings and the methods used. Recommendations for future research are outlined in Chapter 5.

Acknowledgements

This Report has been compiled and edited by the UKCIP Programme Office Team: Merylyn McKenzie Hedger, Megan Gawith, Iain Brown and Richenda Connell, with the assistance of the Science Advisor, Thomas Downing and administrative support from Gordana Bibic. The concept for the UKCIP was developed by David Warrilow and Penny Bramwell of Global Atmosphere Division, DETR. The Programme Office Team would like to thank them for their sustained interest and crucial support throughout the first three years of the Programme.

The UKCIP Steering Committee has met at regular intervals and provided general guidance on the operation of the Programme. The Steering Committee includes: Terry Carrington (Department of Trade and Industry), James Curran (Scottish Environment Protection Agency), Gabrielle Edwards (DETR), Rodger Lightbody (Department of the Environment for Northern Ireland), Graham Mason (Confederation of British Industry), Chris Newton (Environment Agency), Havard Prosser (National

¹ A full list of the publications is provided in Annex 1.1 of Chapter 1.

Assembly for Wales), Mike Roberts (Institute of Terrestrial Ecology), Diana Wilkins (Ministry of Agriculture, Fisheries and Food), Guy Winter (Scottish Executive) and a representative of CAN-UK.

Emerging ideas for future research (presented in Chapter 5) were initially discussed with the UKCIP Science Panel, which includes: Melvin Cannell and Jim Skea (co-chairs), Nigel Arnell, Geoff Jenkins, Jean Palutikof and Martin Parry.

Scoping discussions which contributed to the framing of this report involved Jo Hossell, Mike Hulme and Simon Shackley.

This report is accompanied by a Short Report, which is not a summary but is intended to encourage participation in the Programme. The Short Report, "Climate change: Assessing the impacts – identifying responses. Highlights of the first three years of the UK Climate Impacts Programme" can be obtained from DETR free literature (Product code 00EP0282) or from the UKCIP Programme Office.

EXECUTIVE SUMMARY

I Introduction

This Report presents the work that has been undertaken in the first three years of the UK Climate Impacts Programme (UKCIP). The Programme was established by the Department of the Environment, Transport and the Regions (DETR) with the aim of establishing a research framework for the integrated assessment of climate change impacts in the UK. Its specific objective is to co-ordinate and integrate a stakeholder-led assessment of the impacts of climate change at a regional and national level. Assessments under the UKCIP will provide Government and private sector decision-makers with information needed to underpin the development of strategies to adapt to climate change.

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II Rationale for UKCIP

UKCIP has been based on two main premises. First, that research on climate change impacts which is driven, administered and funded by stakeholders will provide information which meets their needs and helps them plan how to adapt to climate change. Second, that by providing an integrative framework within which studies are undertaken, individual sectors will obtain a more realistic assessment of climate change impacts. This will enable appropriate adaptation strategies to be developed which take account of impacts and interactions across sectors and regions. The assessments will also be used strategically to inform Government policy on the need to mitigate and adapt to climate change.

The Programme is part of the ongoing research strategy on climate change of DETR. To date the main focus of the work of DETR has been mitigation through the reduction of greenhouse gas emissions. If concentrations of carbon dioxide in the atmosphere are stabilised at 550ppm (the level proposed by the EU to guide emissions reduction efforts), temperatures are expected to rise by about 2°C compared to the present day. Thus Government support for the Programme is a recognition that climate change has to be tackled.

III General functioning of UKCIP

At the heart of UKCIP is a small Programme Office which is based in the Environmental Change Institute of the University of Oxford. The Programme is advised by a Steering Committee comprised of representatives of key Government departments, public agencies, the private sector and NGOs. A Science Panel assists in reviewing the integrity of the work and a User Panel will enable stakeholders to interact directly. There are also steering committees for projects operating within the Programme. The Programme currently has no direct funds of its own to undertake research, so it has been working

largely in a 'bottom-up' mode, supporting organisations to initiate studies which assess their own vulnerability and work out their responses - the "stakeholders". It has become a new link between stakeholders and researchers and helps make connections between partners to stimulate a broad-based approach to the study of climate change impacts. In order to generate momentum in the first three years, UKCIP has been opportunistic and responsive to enquiries wherever they have arisen. The conceptual framework is of modular studies, which can be drawn together to prepare an integrated national assessment. Integration is being achieved principally through:

- the common use of core data sets and scenarios;
- co-ordination by the Programme Office through the provision of advice, the facilitation of networking of funders and researchers and the sharing of information;
- developing and applying specific methodologies.

Climate scenarios and socio-economic scenarios have been commissioned for the Programme. Two additional supporting products are currently being developed: one on risk and uncertainty in decision-making, and another on methodologies for costing the impacts of climate change.

IV UKCIP studies

Studies within the Programme fall into two broad groups: sub-UK / regional studies, and sectoral studies which are undertaken in a modular way within a common framework. In the first three years of the Programme the following studies have been undertaken.

IV.1 Sub-UK/regional scoping studies

- Scotland: a scoping study by the Scottish Executive and supported by an advisory committee was launched by Sarah Boyack, Minister for Transport and the Environment, the Scottish Executive on 3 December 1999.
- Wales: a scoping study, was funded by the National Assembly for Wales and supported by an advisory committee, and launched on 18 February 2000 by Peter Law, then Assembly Secretary for Local Government and the Environment, National Assembly for Wales.
- A scoping study for North West England was launched by Michael Meacher, Minister for the Environment on 11 December 1998, funded by a regional consortium of local government, the Government Office for the North West, NGOs and the Environment Agency (EA).
- A scoping study for South East England, funded by a regional consortium of local government, the Government Office for the South East, NGOs, the EA and Country Life magazine, was launched by Michael Meacher, Minister for the Environment, on 25 November 1999.
- A major conference for South West England was held on 28-29 October 1999 to look at the economic impacts of climate change on the region. It was funded by universities, local business, local government, NGOs, the Duchy of Cornwall and the Government Office for the South West. Michael Meacher, Minister for the Environment, delivered a keynote address at the conference.

A scoping study is underway in the East Midlands, and is due to report in June 2000. Scoping studies are at inception in both Northern Ireland and the West Midlands.

IV.2 UKCIP sectoral studies

- Two studies on biodiversity are underway. A scoping study (the DETR/MAFF Biodiversity Review) has been funded by two Government departments, namely the Wildlife and Countryside Directorate of DETR and the Conservation Management Division of the Ministry of Agriculture, Fisheries and Food (MAFF). Another quantitative modelling exercise (MONARCH) is being led

by English Nature and is funded jointly with country agencies (the Countryside Council for Wales and Scottish Natural Heritage), the Environment and Heritage Service Northern Ireland, Dúchas the Heritage Service, National Parks and Wildlife (Republic of Ireland), and three NGOs.

- A scoping study of climate impacts on health is being led by the Department of Health.
- So far, work on the built environment has focussed on developing a project with the Association of British Insurers on subsidence.
- Plans to launch a scoping study on climate change impacts on gardens are underway.

IV.3 UKCIP integrated sectoral study at regional level

- To develop methodologies, a major study (REGIS) has been funded for 2 years by MAFF, the research arm of the water industry (UKWIR) and the DETR's Wildlife and Countryside Directorate. REGIS is undertaking an integrated assessment of four sectors (water, land use, biodiversity and coasts) in two regions in England (East Anglia and North West England).

V Potential vulnerability to climate change: common themes emerging from the Scotland and Wales and English regional scoping studies

The main findings on climate change impacts from the scoping studies are presented on: water; flooding and coasts; the countryside and the business sector.

V.1 Water

Everybody has a water impact of concern, paradoxically both too much and too little. Water resources was identified as a critical issue in all the studies. There was concern over meeting increased summer water demand with reduced and more variable precipitation, or coping with the implications of heavier winter rainfall. The impacts of reduced summer rainfall will affect not only Eastern and South East England but droughts in living memories have caused problems in Wales, South West England and North West England, and these have influenced stakeholders responses. Of particular concern to the South East of England is the impact of 'back to back' droughts and possible over abstraction of aquifers. With nearly 60% of water abstracted in Wales currently exported to England, and demand for Welsh water likely to increase in both Wales and England, it is recognised in Wales that water resource issues will assume a higher profile. Contrasting challenges emerge in Scotland where generally plentiful water resources are likely to increase.

Given that water storage facilities are typically at excess capacity at the start of winter, higher runoff and excess surface water are likely to become more problematic. This has implications for water quality and waste-water storage and treatment. A finding common to all the studies is that the effects of climate change on precipitation patterns, demand management measures, agricultural and urban run-off and increased temperatures will influence water quality. The issue was highlighted in the North West England and South East England studies, the latter concluding that the combined climate impacts on water resources may result in a serious deterioration in water quality in some chalk streams.

V.2 Flooding and coasts

Rising sea-levels, and the potential for increased storminess, leading to increased risk of coastal and river flooding were identified as being of serious concern to a host of interests around the UK. This issue assumed major importance in Scotland, Wales, North West England, South West England, and

the South East coast of England¹. The coast of South East England, for instance, is highly developed with near-continuous sea defences around 1200 km of coast. Older coastal protection schemes did not factor in sea level rise although this is addressed in normal programmes of renewal and refurbishment. Many cities and major facilities (e.g. energy and chemical plants) are sited in coastal locations, such as the Cumbrian coast and Mersey, Ribble and Lune estuaries in North West England. Other vulnerable estuaries were identified in the studies as the Loughor, Tywi and Mawddach in Wales and the Arun in South East England.

Increased flood risk in estuaries and river floodplains could not only affect industry, but also transport and other infrastructure (such as ports) and utilities, as well as the natural environment. Much low-lying coastal land has critical importance economically, for human habitation, for tourism, or for its natural habitats. Threatened areas identified in the scoping studies include the Gwent levels, Denge Peninsula, North Kent coastline, Isle of Sheppey, Somerset levels and the Isles of Scilly. In addition some steep-sided valleys in South West England are particularly vulnerable to flash floods.

Significant marine impacts relate to fisheries where vulnerability was identified in both the South West England and Scotland work. Recent declines in both migratory salmon and some marine species may be linked to fundamental changes in ocean circulation around Scotland, whilst anecdotal evidence suggests warm-water species are being observed more frequently off the Cornish coast.

V.3 The countryside

Impacts of climate change are most powerfully expressed for general public awareness-raising through indicating possible changes to the areas where people live and go to enjoy themselves. By looking comprehensively at a range of sectors, the scoping studies have made visible the significance of this issue. Although the main changes to agriculture, forestry and biodiversity which can be expected in the UK have been covered in work previous to UKCIP, investigations on the broader countryside have formed an important part of all the studies. Vulnerable areas have been identified throughout the UK. Wales and South West England with their high quality rural landscapes and a high proportion of coasts and land designated for environmental protection, are considered to be particularly vulnerable to climate change impacts, Scotland considers its natural environmental resources to be the single sector most likely to be affected by climate impacts. Some of the UK's most distinctive landscapes are likely to be affected by the changing climate including the Hampshire Downs, South Downs and New Forest in South East England, the uplands of Wales, the Lake District, the Cairngorms and more generally estuaries and wetlands.

Whilst agriculture is generally considered adaptable to climate change, each study raised challenging issues.

The scoping studies suggest that the main threat to farmers in the North West of England and Scotland arises from heavier winter rainfall which is likely to present considerable operational difficulties with waste water management systems, and the use of machinery on waterlogged land. Droughts could pose major problems to farmers in the south of the UK where water shortages could affect crop production. Horticulture in North West England could be similarly affected by water supply problems. Opportunities for more widespread crop production earlier in the season could result in South West England losing its current comparative advantage over other regions for certain products. New crop opportunities may emerge in many parts of the UK.

Forestry is one activity likely to benefit from climate change, though with possible changes to species grown. Scoping studies implied that elevated temperatures and carbon dioxide concentrations will increase growth and yields, but increased damage from wind, fire and pests or diseases are causes of concern in all regions.

¹ Results from the REGIS study in East Anglia are not yet available, but the issue here is long recognised

V.4 Business impacts

So far, work within the UKCIP has failed to significantly engage the business community outside the water and insurance sectors (which are already well-informed). There are several reasons for this situation:

- Currently many businesses have short-term planning horizons and do not rate climate change as important relative to other social and economic changes. Furthermore: ‘Within businesses a two year plan is rare and a 20 year plan unreal’ - climate change requires a change to planning horizons for many firms.
- Some studies found that there was very limited understanding of the potential impacts of climate change in some sectors. In part this is due to the fact that the economy of the UK is dominated by the service industry, which appears to be less sensitive than other businesses to the direct impacts of climate change, in the UK.
- Resources available to the study teams did not in all cases allow time for in-depth development of a relationship with the business constituency. Within the private sector, large organisations have managers responsible for a wider range of environmental affairs of which climate change impacts is just one item. And, most SMEs cannot afford staff time to go to steering committee meetings, workshops etc.
- Some large and multi-national companies which do work to long planning horizons prefer to address climate change as a strategic, commercially sensitive issue and may not see the benefits from working with others. It is however surprising that, in some cases, whilst green credentials, with customers and government can apparently be gained by working openly on mitigation issues, little kudos is perceived in working on direct physical impacts of climate change.

Whatever the reason, the preliminary work from the studies showed that there are potentially substantial issues for businesses. Tourism operators in the South West of England, for example, thought that there may be opportunities for extending the holiday season. Enterprises that are reliant on water supplies in South East England and chemical plants in coastal locations of North West England were also aware of their vulnerability to climate change. In Scotland both the service and manufacturing businesses were concerned about the impacts of extremes of temperature, rainfall and storms on buildings and communications structures.

VI Possible adaptation responses: common themes emerging from the Scotland and Wales and English regional scoping studies

VI.1 The challenge ahead

Most of the studies recognised that coping with climate change – adaptation – will involve new approaches to planning. Climate change with the time horizons of the climate models, of 2020’s, 2050’s and 2080’s requires a type of long term strategic planning which has not been undertaken so far in the private sector and also has not been seen in the public sector. Furthermore, whilst developments in modelling and techniques will improve, decision-makers will never have complete information about the future and will have to accept some uncertainties. One other distinctive feature of the climate change issue which was identified in the scoping studies was its wide ranging scope. Because of the interconnections, more effort will have to be made to establish ‘joined-up thinking’ and ‘integrated planning’. Climate change will need to become part of the currency of every decision-maker, not just the experts. However, there are potential mechanisms which could be used more widely such as Regional Planning Guidance (RPG), Local Environment Agency Plans (LEAPs), Biodiversity Action Plans (BAPs) and Shoreline Management Plans (SMPs). In addition existing agri-environmental schemes, such as Tir Gofal in Wales, could be used to achieve integrated planning. The

need to cover climate change through a type of contingency planning, is already working in the planning of coastal and water infrastructure. The North West study suggested that climate change 'headroom' could be extended to include issues such as waste water management, working conditions, insurance and process design. Not only will new problems have to be faced but old problems may re-emerge, such as the remobilisation of metalliferous and toxic wastes with increased precipitation and flooding. In order to exactly assess how climate change will interplay with existing known problems, sound baseline information would be a useful starting point.

Consultation with stakeholders within the studies showed that there is need for better communication and awareness-raising about the potential impacts of climate change and the need for adaptation responses in sectors which have short time planning frames and whose normal activities do not involve dealing with the physical environment. Organisations need to see the opportunity costs and other benefits from their investments. (This involves principally businesses in the manufacturing and service sectors and the tourism industry).

Informed sectors (such as water and other utilities, and environmental protection), have indicated that the barriers to taking adaptive actions are: the lack of financial resources to speed up programmes of physical infrastructure and the will needed to overcome institutional inertia and create these resources. There is also a strongly perceived need that more certain information is required about impacts before significant action can be taken.

VI.2 Water adaptation issues

Water resources is one issue where a national framework needs to be considered before adaptation measures can usefully be finalised at a sub-UK level. Adaptation options in the water sector are defined, but it is recognised that they may be difficult to implement and will be expensive, making the sector very vulnerable to climate change. South East England expects problems in meeting growing demands for water resources under climate change. This may have knock-on effects by placing demands on other regions. There may be pressure from water companies to increase the number or size of reservoirs to store winter rainfall. Availability of water resources is not yet a major factor in the location of new housing growth in the UK but it may become so. The Wales study stated that water resource issues were set to assume a higher profile with climate change with the need to consider ways to reduce demand as well as to increase supplies.

Regional climate model data will be needed to provide more precise information about water resources adaptation requirements at the individual river catchment level. That information will also be needed to address the related water quality concerns which may affect the countryside more generally. New methodologies being developed within the Programme, notably in the REGIS study, could provide helpful guidance to other areas if resources are available.

V1.3 Flooding and coasts adaptation issues

Flood defence was identified as a major issue in many of the regional studies with the Wales study identifying a need for clearer and more transparent presentation of responsibilities and stating that financing is needed for effective adaptation. Measures are already in hand to produce revised guidance for development planning in flood prone areas on rivers and the coast. Some strategic types of adaptation measures have been affected, such as the need to incorporate sea level rise allowances in coastal defence planning and management. However, the incorporation of other potential climate change impacts, such as storm surges in hard engineering works, and other management options, such as managed retreat, will require more information before action is prudent. From the review of work that has been undertaken outside UKCIP and from the REGIS project, it is clear that obtaining such information could be no mean task. Two requirements are clear. Priorities for more research should be established which will include intelligent downscaling of climate data and the generation of more information on extreme events. Also a significant effort is needed to collate relevant data sets into

accessible formats to ensure that work which has been undertaken so far is readily accessible within the public domain.

VI.4 Countryside adaptation issues

Headline issues for adaptation in the countryside which were identified in the studies include: land management to limit erosion and stress upon upland vegetation, factoring climate change into site designation systems, proposals for habitat corridors, and opportunities for farmers to plant new crops.

It is still possible to identify basic research needs, for example, on water quality and soils. This is partly because developments in technology can allow more complex, integrated research to be undertaken, and the interconnections between systems can be modelled. This is despite the fact that considerable work on agriculture has been undertaken previously outside the UKCIP framework; and that within UKCIP, there are key projects (REGIS, MONARCH and the DETR/MAFF Biodiversity Review) which have yet to report. Nor is that the only difficult part. Results emerging so far suggest that decision-makers may need to consider changes to their current ways of operating. The studies show that existing policy frameworks such as landscape protection measures, biodiversity conservation systems and other conservation policies and measures could need to be integrated more systematically to allow for adaptation. More positively, these existing mechanisms do mean that ways exist which can potentially be modified to facilitate adaptation.

VII Key findings about the effectiveness of UKCIP

Significant progress has been achieved during the first three years' operation of the UKCIP.

- UKCIP has managed to capture the considerable interest that exists in many organisations to make the global problem of climate change into an accessible issue at regional and local scales. Through its support to the informal climate groups that now exist throughout the UK, UKCIP has enabled a wide range of stakeholders to become involved in studies.
- The basic institutional framework of the Programme has proved robust to accommodate a range of impacts assessments. A variety of scientific studies is underway through collaborative efforts by organisations which would not normally have worked together. Overall, UKCIP has been the route to collective effort and the mobilisation of resources. Many organisations perceive advantages to working within the broad umbrella of the Programme.
- UKCIP has bridged the science and policy worlds and has enabled stakeholders to define a research agenda which is linked to their needs. A range of approaches have been forged which turn stakeholder engagement into involvement on assessing climate change impacts.
- Whilst not focused on public awareness-raising, the considerable media coverage generated by the launch events, particularly in regional media, has made the impacts and adaptation issue a reality for many people.
- Advantages of the linking and networking opportunities provided by the Programme are visible. For example, the studies in the biodiversity sector have been able to inform each other.
- Through the Programme, new climate change and socio-economic scenarios have been developed and widely promoted: the climate change scenarios are now widely used in the UK.
- A synthesis of current knowledge on impacts to inform the adaptation agenda has been provided for policy-making.
- Barriers to research and action have been identified.

VIII Implications of results

VIII.1 Improvement of UKCIP Structure and Methods: Perspectives of stakeholders

a) Uncertainty

Reluctance to take action to adapt to climate change was found in the stakeholder surveys to be linked to the uncertainties about what is going to happen. This attitude emphasises the importance of understanding the impacts of climate change, so that adaptation is geared to respond to those impacts. How much needs to be known about the different impacts' sectors to trigger changes in decision-making by key stakeholders? Current work with the Environment Agency on risk and uncertainty in decision-making for UKCIP is intended to give guidance to non-specialists about tools which they can use to cope with uncertainty. More attention will probably need to be given to unpacking its outputs, including the development of visualisation tools to explain the decision-making processes involved. If decision-makers feel more confident about handling the inevitable uncertainties inherent in the climate change issue, they may be more prepared to take action and start adaptation.

b) More detailed climate models

A universal request is for more detailed, regional-scale climate models. Perhaps surprisingly, the effort of the Programme to provide information on a range of possible outcomes through providing the four climate scenarios, has not meant that many studies have used these.

All studies face resource constraints on the information that can be handled, and most studies have drawn most heavily on the medium high scenario for which more information is provided.

c) Extreme weather events

Extreme weather events act as useful reference points to explain the potential impacts of climate change and are acknowledged to be powerful drivers for action. More information is sought by stakeholders about their anticipated changing frequency and severity at regional scales. This again will require the use of regional models.

d) Readily accessible data-sets and information

Sectoral studies within UKCIP have experienced substantial delays due to the lack of ready access to data-sets and the absence of a common format. This problem is not confined to the Programme. Lack of local data to validate models has been identified elsewhere and even where data-sets do exist concerns have been expressed as to their accuracy.

VIII.2 Next stages for UKCIP

Within the Programme, there has been a long-standing intention to:

- Prepare model study toolkits;
- Provide better information on research already completed on impacts assessment and adaptation;
- Reinforce links between regional and sectoral studies;
- Provide guidance on use of supporting products, such as scenarios.

This review underscores the need for this work to be undertaken, and also:

- The scope for further development of the UKCIP underpinning products: climate scenarios, socio-economic scenarios and the GIS;
- The need for improved capacity within study teams to tackle social and economic impacts;
- More attention to be given to constructing an economic framework for studies, within the UK, and the global context;
- Provision should be made to develop visualisation tools within the Programme in association with projects underway;

- The need for development of monitoring tools at a regional level on indicators and the impact of extreme weather events;
- Detailed survey work on stakeholder attitudes would help develop a clearer view on what motivates or deters action on adaptation. The awareness-raising dimensions of UKCIP could then be better targeted.

VIII.3 Future Research Priorities

Considerable effort is being expended to improve understanding of the key impacts of climate change, but there are many outstanding questions to be answered. Box 1 summarises the research questions that have emerged from UKCIP sub-UK scoping studies. New research is already starting on some of these questions, for example, water quality.

Box 1: Future research questions highlighted in UKCIP sub-UK scoping studies

More detailed regional climate and extreme events information: Will climate change be the same over a range of habitats and localities? (Wales/Scotland) An improved understanding of how climate change will affect extreme events is urgently required (South East). Further data... on changing patterns of precipitation and snowfall (Scotland).

Flooding: Will climate change make flooding events more frequent? (Wales/Scotland). How should opportunities for managed retreat be evaluated? (North West). More research is urgently needed into coastal erosion processes (Wales). How can climate change impacts be accounted for in protecting the floodplain? (South East).

Water resources & hydrology: How will water quality in chalk streams be affected by climate change? (South East) What are the ecological impacts of low and/or more variable and extreme water flows in rivers, streams and lakes? (North West)

Biodiversity, agriculture and soils: How much will climate change interact with other environmental pressures ... in shaping the future of vulnerable habitats? (Wales). Will climate change increase or decrease soil erosion on agricultural lands? (North West)

Business & Tourism:

Will businesses adapt and take on the challenges created by changes in recreational patterns, tourist preferences and domestic lifestyles? (South East) The raft of business opportunities associated with climate change issues should be explored (Scotland). More information is required on the complex relationship between climate and tourism (South West).

Cultural heritage: How should the risks and costs of maintaining historic buildings under a changed climate be managed? (South East)

UKCIP recommends a portfolio of future studies, ranging from scoping studies for sectors where little or no impacts information is available, to other sectors where detailed quantitative research is required to answer important questions. The research portfolio is summarised in Figure 1. UKCIP will seek to secure resources for these studies, which are needed to achieve a national assessment of climate change impacts, through work with stakeholders and other organisations. This is an ambitious agenda and will require the commitment of additional resources for research.

Gaps where scoping studies would be useful are:

- London;
- East Anglia;
- marine environment;
- tourism;
- transport and the built environment (to cover impacts on manufacturing plant and service industries);
- energy;

- urban areas;
- cultural heritage.

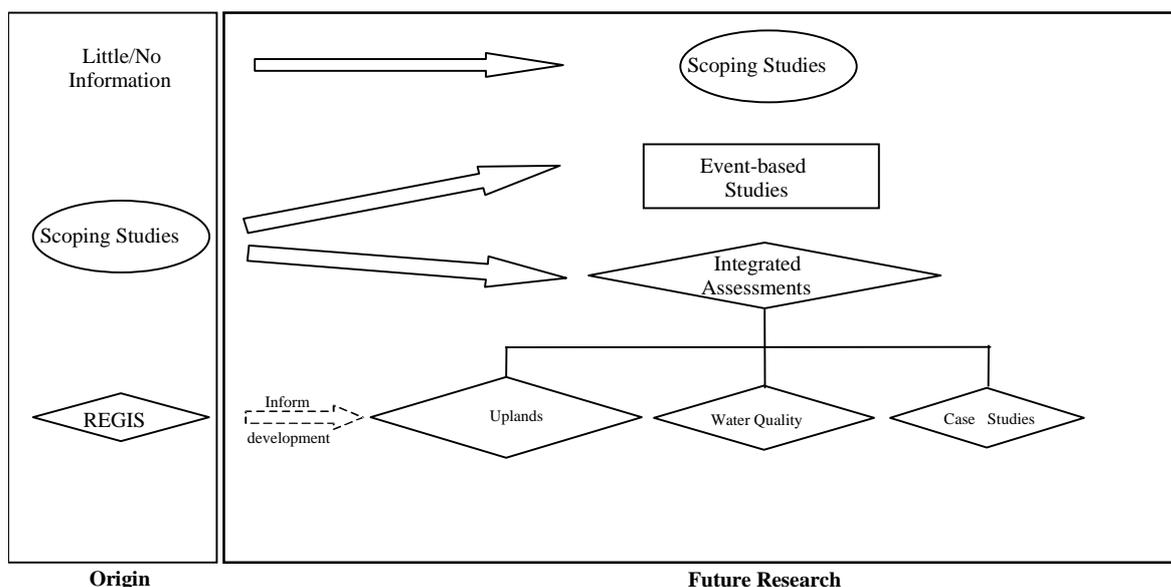


Figure 1: Key issues emerging from completed and ongoing studies (left hand column) have enabled the development of a portfolio of future research priorities (right hand column) .

“What if” event-based studies provide insight into the sensitivity of the UK economy to climate variability and change. “Event-based” studies could include, for example, specific historic events, for which data on impacts might be available. Alternatively, studies could examine theoretical weather events suggested by climate models, covering:

- impacts of three successive dry years (e.g. 1995);
- impacts of three successive wet autumns and winters (e.g. 1998);
- impacts of an extended drought followed by a period of intense rainfall and stormy weather (e.g. 1976).

Integrated Assessments: Based on the REGIS methodology, two new studies could be undertaken:

- integrated assessment of vulnerable upland areas, such as in Scotland and Wales, (and possibly other parts of the UK) including additional factors such as forestry, soil erosion and farm animal stocking;
- an integrated assessment of climate change impacts on water quality, including within-sector adaptation measures and examining the effects of extreme events.

Quantitative assessments in key sectors: Assessments of climate change impacts across sectors requires very intensive data and resources, so it is not feasible to do detailed assessments for the UK as a whole. One way forward would be to identify areas particularly at risk from climate change and undertake detailed assessments for those areas. Quantitative assessments could address the issues in Box 2.

Box 2 Issues to be addressed by quantification studies

Coasts:

- Quantify more accurately the local impacts of sea-level rise*.
- Quantify changes in the magnitude and frequency of storm surges, wave heights and tidal dynamics.
- Focus on holistic case studies of vulnerable areas, including The Solent (with Chichester Harbour), Morecambe Bay and the North Norfolk Coast, integrating offshore and onshore environments.
- Evaluate the feasibility of intervention policies, such as managed retreat, at key sites. Will this produce salt marsh at different sites around the UK?
- Evaluate the threat of saline intrusion into valuable coastal soils.

Water resources and hydrology:

- Quantify impacts using more detailed catchment-based case studies, incorporating the future risk of droughts, and occurrence of back-to-back drought years.
- More accurate catchment models are required, driven by hourly/daily climate scenario data, to improve information on water quality impacts.
- Evaluate changing seasonal variations of groundwater reserves.
- Investigate the effects of socio-economic and regulatory changes on water demand.
- Can current institutional structures respond to future extreme events?

Soils, Agriculture and Biodiversity

- Investigate the response of soil micro-organisms to a changing climate, and implications for decomposition of organic matter and the role of soils in the carbon cycle.
- What effect will vegetation changes have on soil formation, and what feedbacks operate?
- Examine the rates of habitat and species migration under climate change.
- Research is needed on effects of changed seasonal climate variables.
- New studies are needed on agricultural water use and water quality changes.
- Integrated studies of agriculture and biodiversity.
- Investigate the potential effects of new crops on soil nutrient cycling.
- Research should be linked in to improved monitoring networks.

* *The second round of Shoreline Management Plan studies (due to commence in 2001/2002) should make significant progress in addressing the first three points.*

GLOSSARY

| | |
|-----------------|---|
| ABI | Association of British Insurers |
| BAP | Biodiversity Action Plan |
| BAGEC | Biological Adaptations to Global Environmental Change |
| BRE | Building Research Establishment |
| CCIRG | Climate Change Impacts Review Group |
| CHaMP | Coastal Habitat Management Plan |
| CO ₂ | Carbon dioxide |
| CPO | Core Programme Office (of the UK Climate Impacts Programme) |
| CRU | Climatic Research Unit, University of East Anglia |
| CSO | Combined Sewer Overflow |
| DANI | Department of Agriculture, Northern Ireland |
| DETR | Department of the Environment, Transport and the Regions |
| DoE | Department of the Environment |
| DH | Department of Health |
| EA | Environment Agency |
| ESA | Environmentally Sensitive Area |
| GAD | Global Atmosphere Division |
| GCM | Global Climate Model |
| GIS | Geographical Information System |
| GPS | Global Positioning System |
| IPCC | Intergovernmental Panel on Climate Change |
| ITE | Institute of Terrestrial Ecology |
| LEAPS | Local Environmental Action Plan |
| LIDAR | Light Detection and Ranging |
| MAFF | Ministry of Agriculture, Fisheries and Food |
| MLURI | Macaulay Land Use Research Institute |
| MONARCH | Modelling Natural Resource Responses to Climate Change |
| NERC | Natural Environment Research Council |
| NGO | Non-Governmental Organisation |
| NNR | National Nature Reserve |
| NSA | Nitrate Sensitive Area |
| NVZ | Nitrate Vulnerable Zone |
| PCA | Principal Components Analysis |
| Ramsar | Designated wetland conservation area based on Ramsar Convention |
| RCM | Regional Climate Model |
| REGIS | Regional climate change impact and response studies in East Anglia and North West England |
| SAC | Special Area of Conservation |
| SEPA | Scottish Environment Protection Agency |
| SME | Small and Medium sized Enterprise |
| SMP | Shoreline Management Plan |
| SNH | Scottish Natural Heritage |
| SNW | Sustainability North West |
| SPA | Special Protection Area |
| SPRU | Science Policy Research Unit, University of Sussex |
| SRES | Special Report on Emissions Scenarios |
| SSLRC | Soil Survey and Land Research Centre |
| SSSI | Site of Special Scientific Interest |
| TIGER | Terrestrial Initiative on Global Environmental Research |
| UKCIP | UK Climate Impacts Programme |
| UKWIR | UK Water Industry Research |
| VOC | Volatile Organic Compound |

Chapter 1

The UKCIP Framework

Merylyn McKenzie Hedger, Mike Hulme and Iain Brown

1.1 Introduction to UKCIP

1.2 Tools for integrated assessment

1.3 Providing access to information and data

1.4 Conclusions

1.5 References

Annex 1.1 List of publications produced in the first three years of UKCIP

Annex 1.2 Background information on UKCIP

This Chapter explains the aims and framework of the UK Climate Impacts Programme (UKCIP), established by DETR, which has led to a number of stakeholder-funded studies being completed in the United Kingdom. The Programme has involved organisations which have been working on climate change impacts for many years, such as the Environment Agency and Ministry of Agriculture, Fisheries and Food (MAFF), and has also been able to engage organisations new to climate change impacts research in local and regional government. An integrating framework has been provided by DETR, which operates through the Programme Office of the UKCIP. The framework has worked effectively principally through the application of the climate change scenarios. Consolidation of the framework is underway, through the development of socio-economic scenarios, guidance on risk and uncertainty in decision-making and the development of a methodology for costing the impacts of climate change.

1.1 Introduction to UKCIP

1.1.1 Rationale

The UK Climate Impacts Programme brings together organisations in the public and private sectors to undertake sectoral- and sub-UK impact assessments. UKCIP has been based on two main premises. First, that climate impacts research driven by stakeholders will provide information which meets their needs and helps them plan how to adapt to climate change. Secondly, that by providing an integrative framework within which studies are undertaken, individual sectors will obtain a more realistic assessment of climate change impacts. This will enable appropriate adaptation strategies to be developed which take account of impacts and interactions across sectors and regions. The assessments will also be used strategically to inform Government policy on the need to mitigate and adapt to climate change.

The Programme is part of the ongoing research strategy on climate change of the Department of the Environment, Transport and the Regions (DETR), which has the lead within Government on the issue. To date the focus of main Government policy has been mitigation through the reduction of greenhouse gas emissions. However, if concentrations of atmospheric CO₂ are stabilised at 550ppm (the level proposed by the EU to guide emissions reduction efforts) temperatures are still expected to rise by about 2°C compared to the present day. Thus, Government support for the Programme recognises that climate change impacts have to be tackled.

At the heart of UKCIP is a small Programme Office based in the Environmental Change Institute of the University of Oxford. The Programme is advised by a Steering Committee comprised of representatives of key Government departments, public agencies, the private sector and NGOs (see Figure 1.1a). A Science Advisory Panel oversees the integrity of the work. A User Panel will be established to enable organisations seeking to work on climate change impacts to interact directly with the Programme. There are also now a number of steering committees for projects operating within the Programme (see Table A1.2a in Annex 1.2).

The Programme currently has no direct funds of its own to undertake research, so it has been working largely in a ‘bottom-up’ mode, supporting organisations - the “stakeholders” - to initiate studies which assess their own vulnerability and work out their responses. It has become a new link between stakeholders and researchers and helps make connections between partners to stimulate a broad-based approach to the study of climate change impacts. In order to generate momentum it has been opportunistic and responsive to enquiries wherever they have arisen. The conceptual framework is of modular studies, which can be used to prepare an integrated national assessment.

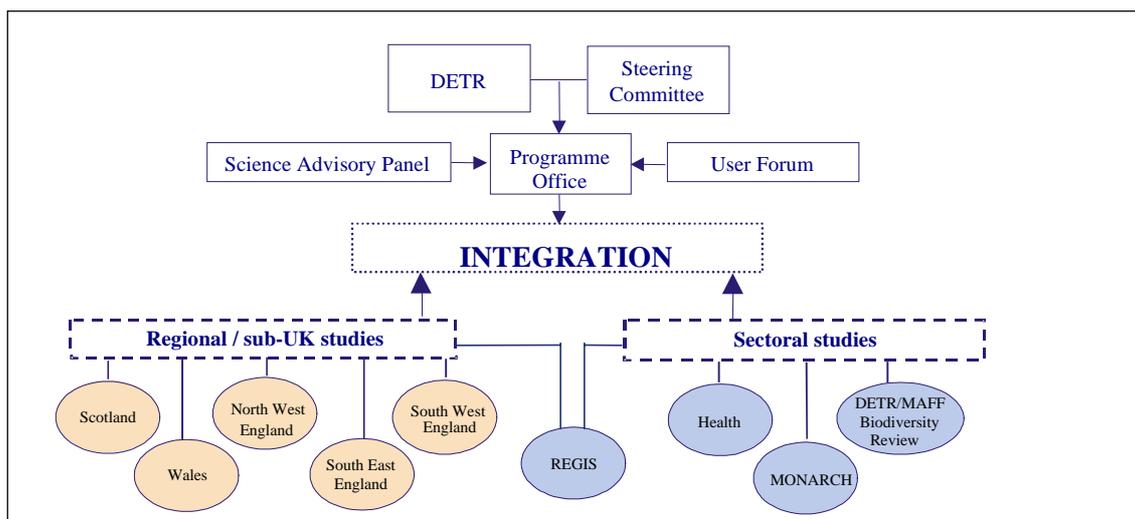


Figure 1.1a: Structure of the UKCIP and studies reported on in this document.

DETR has funded the development of core products to support studies and to facilitate integration. These are discussed further in Section 1.2.

Considerable dynamism has developed within the Programme through the sub-UK scoping studies, which have engaged a wide range of stakeholders as funders. Early studies have become reference models for other scoping studies in Wales and England and each has sequentially developed the methodology. Furthermore, the results of studies have been successfully publicised through ‘launch’ events, creating wide public awareness (see Table A1.2b in Annex 1.2). The information in the scoping studies was collected mainly by literature review, use of expert judgement and interviews with key stakeholders.

Early sectoral studies, specifically REGIS¹ and the DETR/MAFF Biodiversity Review were developed with the co-operation of other Governments departments. Where studies have not been thought to meet needs fully, complementary studies have been commenced; for example, a quantitative modelling exercise on biodiversity, the MONARCH study, followed the DETR/MAFF Biodiversity Review.

¹ The REGIS study, an integrated study of natural resources across regions and sectors, arose through the consultation process on the scoping study by SPA and ESYS which led to the formation of UKCIP (See Section A1.2.3 in Annex 1.2).

1.1.2 Overview of integration

As the UKCIP has been operationalised, the means of achieving integration have focused on:

- the use of common scenarios (climate and socio-economic);
- the use of common data-sets;
- activities of the Programme Office in providing advice before and during the commissioning of studies, monitoring progress, maintaining momentum of projects, facilitating effective networking, and disseminating information about the Programme, activities within the Programme and wider developments; and,
- the development of specific methodologies, currently principally through the REGIS project which has yet to be completed.

An overview of the integration framework of the UKCIP in terms of activities and roles is provided in Figure 1.1b.

Through disseminating information, the Programme Office (PO) of UKCIP has raised awareness of climate change issues amongst stakeholders, developed networks of users, and acted as a conduit of climate change impacts information between users and researchers. Dissemination has been achieved through:

- A regular newsletter;

- Technical reports;
- Informal guidance notes;
- Presentations to a wide range of audiences;
- Hosting events for specialist audiences.

Media coverage of the impacts of extreme weather events in the UK and elsewhere is now being recorded in a systematic way. An improved documentation centre is now also available to users. An inventory of UK research projects on climate change impacts has also been compiled, containing details of approximately 250 studies. This inventory is currently incomplete, but will be developed more fully in the future.

Information about the Programme has been disseminated through presentations at a range of events by UKCIP and DETR staff. At least 200 events have been covered ranging from international meetings and a CBI briefing to a Farmers Breakfast Club.

1.1.3 UKCIP studies to date

UKCIP sub-UK scoping studies

In the first three years of activity, the following sub-UK studies have been completed or are underway:

- Scotland – a scoping study funded by the

Scottish Executive (then The Scottish Office) and supported by an advisory committee was launched on 3 December 1999 by Sarah Boyack, Minister for Transport and Environment, the Scottish Executive.

- Wales – a scoping study, funded by the National Assembly for Wales (then the Welsh Office) and supported by an advisory committee was launched on 18 February 2000 by Peter Law, then the Secretary for Local Government and the Environment, the National Assembly for Wales.
- A scoping study for North West England was launched by Michael Meacher, Minister for the Environment, on 11 December 1998, funded by a regional consortium of local government, the Government Office for the North West, non-governmental organisations (NGOs), and the Environment Agency (EA).
- A scoping study for South East England, funded by a regional consortium of local government, the Government Office for the South East, NGOs, the EA and Country Life magazine, was launched by Michael Meacher, Minister for the Environment on 25 November 1999.
- A major conference for South West

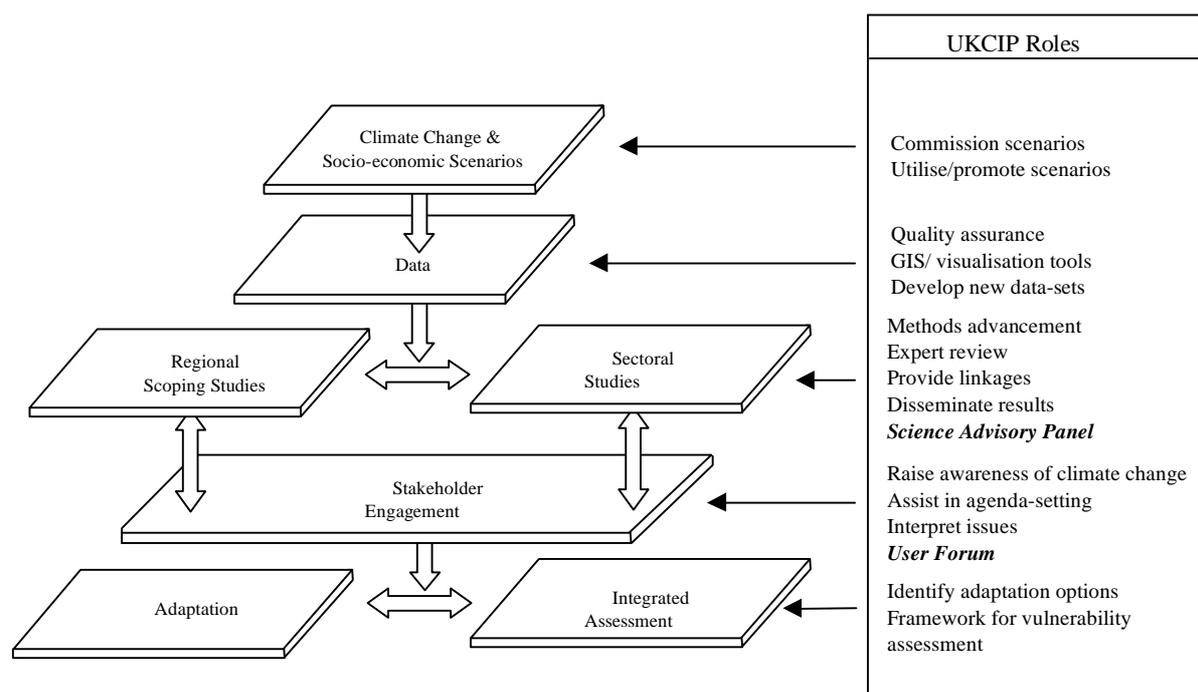


Figure 1.1b Co-ordination of activities and roles within the UK Climate Impacts Programme

England was held on 28-29 October 1999 to discuss the economic impacts of climate change on the region. It was funded by regional universities, local business, local government, NGOs, the Duchy of Cornwall and the Government Office for the South West. Michael Meacher, Minister for the Environment, delivered a keynote address at the event. Reports from the Conference and other outputs will steer next stage work.

- A scoping study is underway in the East Midlands and is due to report in June/July 2000. Scoping studies are at inception in both Northern Ireland and the West Midlands.

UKCIP sectoral studies

- Two studies are underway on biodiversity. The DETR / MAFF Biodiversity Review study has been funded by two Government departments, the Wildlife and Countryside Directorate of DETR and the Conservation Management Division (CMD) of MAFF. Specialised agencies and NGOs are funding a quantitative modelling exercise (MONARCH), led by English Nature.
- A scoping study of health impacts is being led by the Department of Health.
- So far work on the built environment within the Programme has focussed on developing a project with the Association of British Insurers on subsidence.
- A workshop on the effects of climate change on gardens was held on 6 April 2000. The workshop was organised by UKCIP, The National Trust and The Royal Horticultural Society, to initiate a study on gardens.

UKCIP integrated sectoral study at regional level

To develop methodologies, a major study (REGIS) has been funded for 2 years by the Ministry of Agriculture, Fisheries and Food (MAFF), UKWIR and the DETR's Wildlife and Countryside directorate. Funds for the project total £300,000. REGIS is conducting an integrated assessment of four sectors (water

resources, land use, biodiversity and coasts) in two English regions (East Anglia and North West England).

A full list of publications is provided in Annex 1.1. Funders of, and researchers on UKCIP studies to date, are listed in Box A1.2a and A1.2b respectively of Annex 1.2.

1.2 Tools for integrated assessment

As outlined in Section 1.1.2 one principal method whereby integrated assessment is to be achieved for the UK is through the use of common tools for climate impacts assessment. A robust framework of possible futures – both climate and socio-economic ‘scenarios’ – is required as a basic input to UK impacts assessments, and to facilitate the integration of results from all UKCIP studies. Such a framework will enable organisations to assess their vulnerability to change against a broad range of futures, and to prepare an appropriate range of responses. Because a large number of uncertainties are inherent at all stages of climate change impacts research, guidance is being prepared for UKCIP studies on how to handle risk and uncertainty in decision-making (Section 1.2.4). In addition a methodology for costing the impacts of climate change is now being developed (Section 1.2.5). This section provides details of underpinning products funded separately by the DETR for use by studies conducted within the Programme.

1.2.1 Climate change scenarios

A new set of climate change scenarios was commissioned by the DETR from the University of East Anglia's Climatic Research Unit and the Hadley Centre. The report on climate change scenarios, entitled *Climate Change Scenarios for the United Kingdom* (Hulme and Jenkins, 1998) was launched in October 1998. The scenarios have been used in all UKCIP studies to date and have proved to be a critical means of facilitating integration between studies.

What are climate scenarios?

Climate scenarios present coherent, systematic and internally-consistent descriptions of changing climates. Scenarios are typically used as inputs into climate change vulnerability, impact or adaptation assessments, but are used in many different ways by many different individuals or organisations. Some studies may require only semi-quantitative descriptions of future climates, perhaps as part of a scoping study. Others may need quantification of a range of future climates, perhaps with explicit probabilities attached, as part of a risk assessment exercise, and others require information for very specific geographical areas. There is also a range of time horizons that may be considered relevant, depending on the type of decision to be made. Water companies may be concerned with operating conditions over the near-term (10-20 years), while coastal engineers or forestry investment decisions may need to consider longer-term horizons.

Climate scenarios are most commonly constructed using results from global climate model (GCM) experiments. These model experiments provide fairly detailed descriptions of future climate change, but GCM-based scenarios are uncertain descriptions of future climate for a number of reasons. A fundamental source of uncertainty in describing future climate originates from the *unknown world future*. How will global greenhouse gas emissions change in the future? Will we continue to be dominated by a carbon-intensity energy system? What environmental regulation may be introduced to control such emissions?

Different answers to these questions can lead to a wide range of possible emissions scenarios. Since any GCM climate change experiment has to choose an emissions scenario, different choices can lead to quite different climate outcomes. The main *modelling uncertainties* in climate change

prediction stem from: different estimates of the climate sensitivity (ie. the sensitivity of the climate to a doubling of atmospheric carbon dioxide concentrations); the contrasting behaviour of different climate models in their simulation of regional climate change; and internal variability of the climate system. These latter differences are largely a function of the different schemes employed to represent important processes in the atmosphere and ocean (known as parameterisations) and the relatively coarse resolutions of the models. In the Hadley Centre GCM, for example, the UK land area is represented by just four gridboxes, making it impossible to differentiate between the climate change predicted for, say, the Lake District and Merseyside or for the Wash and the Thames Estuary.

For these two reasons, namely unknown future emissions and uncertainties in climate modelling, it is preferable to talk about future climate *scenarios* rather than about future climate *predictions*.

The UKCIP98 climate scenarios

The climate change scenarios developed for use in UKCIP studies rely largely on two sets of GCM experiments completed by the Hadley Centre during 1995 and 1996. These experiments were undertaken using a coupled ocean-atmosphere GCM called HadCM2. This model has been extensively analysed and validated and represents one of the leading global climate models in the world. It features prominently in the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) due for publication in 2001. The UKCIP98 scenarios have been widely used in UK climate impacts assessments over the last two years. New modelling work is underway in the Hadley Centre and the next set, the UKCIP2001 scenarios, will be published by the end of 2001. Information on the next set of climate scenarios is provided later in this section.

Box 1.2a: The UKCIP98 climate scenario assumptions

- Since no single climate change scenario can adequately capture the range of possible climate futures, four alternative climate scenarios for the UK are presented - **Low**, **Medium-Low**, **Medium-High** and **High**.
- This range of scenarios available derives from different values for the climate sensitivity, from different future levels of anthropogenic forcing of the climate system, and from different global climate models. The range adopted is consistent with the IPCC Second Assessment Report.
- The scenarios result from future changes in greenhouse gases alone. Changes in natural forcing factors such as volcanoes or solar variability are not considered; neither are changes in the concentration or distribution of sulphate aerosols created by human emissions of sulphur dioxide. The effects of sulphate aerosols on climate are highly uncertain, in addition to which their effects are likely to be transitory and of diminishing magnitude, especially over the UK.
- Three future time periods are considered: the 2020s, the 2050s and the 2080s.
- More detail is provided for the **Medium-High** scenario, since more climate model simulations and analyses have been completed under its assumptions than for the other scenarios. The **Medium-High** scenario assumes a future increase of 1% per annum in greenhouse gas concentrations. This is regarded as a convenient assumption of future anthropogenic emissions rather than as a 'best-guess' outcome. Where possible the alternative UKCIP scenarios - **Low**, **Medium-Low** and **High** - should also be used.
- It is assumed that Global Climate Model results have meaning at the scale of individual gridboxes (typically 300-400km²), but are not generally interpreted on smaller scales.

Given the difficulties alluded to above in making firm predictions about future climate, how best to proceed? Do we try and make the 'best' judgement or most likely estimate of future greenhouse gas emissions, employ the 'best' model we can find, and then create the 'best' estimate of future climate change? This is the sort of approach that leads to a 'best guess' or 'business-as-usual' climate scenario. Alternatively, do we consider a wide range of emissions scenarios and climate modelling uncertainties to try and capture a wide range of possible climate outcomes for the UK? In this case we have to judge where the important extremes in the range of possibilities lie, but still keep the number of resulting climate scenarios to a manageable minimum. The approach adopted in the UKCIP98 scenarios was to present four scenarios of UK climate change spanning a 'reasonable' range of possible future climates. These scenarios were labelled **Low**, **Medium-low**, **Medium-high** and **High**, the labels referring to their respective global warming rates. Some of the key assumptions behind the UKCIP98 climate scenarios are listed in Box 1.2a.

The four UKCIP98 scenarios were constructed with the following assumptions:

- **Low:** the IS92d emissions scenario² with a low (1.5°C) climate sensitivity.
- **Medium-low:** the HadCM2 GGd experiment (0.5% per annum increase in equivalent³ CO₂ concentrations and ~2.5°C sensitivity)
- **Medium-high:** the HadCM2 GGa experiment (1% per annum increase in equivalent CO₂ concentrations and ~2.5°C sensitivity).
- **High:** the IS92a emissions scenario⁴ with a high (4.5°C) climate sensitivity.

For these four scenarios, the world warms globally by the 2020s by between 0.6°C and 1.4°C, a decadal rate of warming of between 0.11° and 0.28°C per decade. For comparison, the observed rate of global warming for the

² Global carbon emissions under the IS92d scenario reach just over 10GtC by 2100, compared to about 6.5GtC today.

³ 'Equivalent' carbon dioxide concentrations are used in the HadCM2 experiments because this model cannot handle different greenhouse gases individually. The concentrations used may represent many different possible combinations of carbon dioxide, methane, nitrous oxide and halocarbon concentrations, the sum of which yields the same gross radiative forcing.

⁴ Global carbon emissions under the IS92a scenario reach over 20GtC by 2100.

last two decades has been about 0.14°C per decade. By the 2080s, the UKCIP98 scenarios generate a warming range of 1.1°C to 3.5°C. The global-mean sea-level changes and carbon dioxide concentrations associated with the four UKCIP98 scenarios similarly reflect a range of values that may be used in climate change impacts assessments.

Pre-industrial carbon dioxide concentrations (~275 ppmv) double by the 2050s under the **Medium-high** scenario and the average 1961-90 concentration (~334ppmv) doubles by the 2080s under this scenario. Changes are more modest for the **Low** and **Medium-low** scenarios, so that even by the 2080s concentrations remain below the pre-industrial doubling level (515 and 498 ppmv respectively). Global-mean sea-level rises throughout each scenario, but the rate of rise varies from about 2cm per decade for the **Low** scenario to about 9cm per decade for the **High** scenario.

The UKCIP98 climate scenarios include a range of illustrations about what these scenarios imply for UK climate. These are fully documented in the report by Hulme and Jenkins (1998). Two examples of the type of information in the report are shown in Table 1.2a and Figure 1.2a. Figure 1.2a shows the range of changes in average annual temperature for the UK for each of the four scenarios and for each of the three time-slices. For all scenarios there is a north west to south east gradient in the magnitude of the climate warming over the UK, the south east consistently warming by several tenths of a degree Celsius more than the north west.

Warming rates vary from about 0.1°C per decade for the **Low** scenario to about 0.3°C for the **High** scenario. The distribution of daily temperature extremes also changes in the future and some specific examples are shown in Table 1.2a. Table 1.2b summarises some of the other variables and analyses provided in the UKCIP98 scenarios.

Future developments in climate scenario construction

There are five main sources of uncertainty about future climate that qualify the descriptions of future UK climate given in the UKCIP98 scenarios. With regard to future ‘improvements’ in climate prediction and in climate scenario design, some of these uncertainties may be narrowed, while some will not. These prospects are summarised below:

- *Unknown future greenhouse gas emissions:* This will remain an inherent source of uncertainty for climate prediction. New emissions scenarios may be designed and, as with the new IPCC Special Report on Emissions Scenarios (SRES), they may be designed using improved methodologies. But this will not narrow the range of projections. Indeed, the SRES range of carbon emissions by 2100 is largely similar to the earlier IS92 range. The new UKCIP2001 climate scenarios will be designed around a representative set of the six SRES marker emissions scenarios.

Table 1.2a: Probability of daily temperature extremes for Scotland and South East England derived from the HadCM2 model for the UKCIP Medium-High scenario, expressed in the number of days out of every 100 days on which such conditions could occur. Note: these probabilities are for climate model gridbox regions (~10,000km²) and therefore the absolute probabilities shown will differ from those measured at individual locations.

| Time period | Winter nights below freezing | | Summer days above 25°C | |
|------------------|------------------------------|------------|------------------------|------------|
| | Scotland | SE England | Scotland | SE England |
| Present: 1961-90 | 0.28 | 0.20 | 0.00 | 0.06 |
| Future: 2080s | 0.11 | 0.07 | 0.01 | 0.18 |

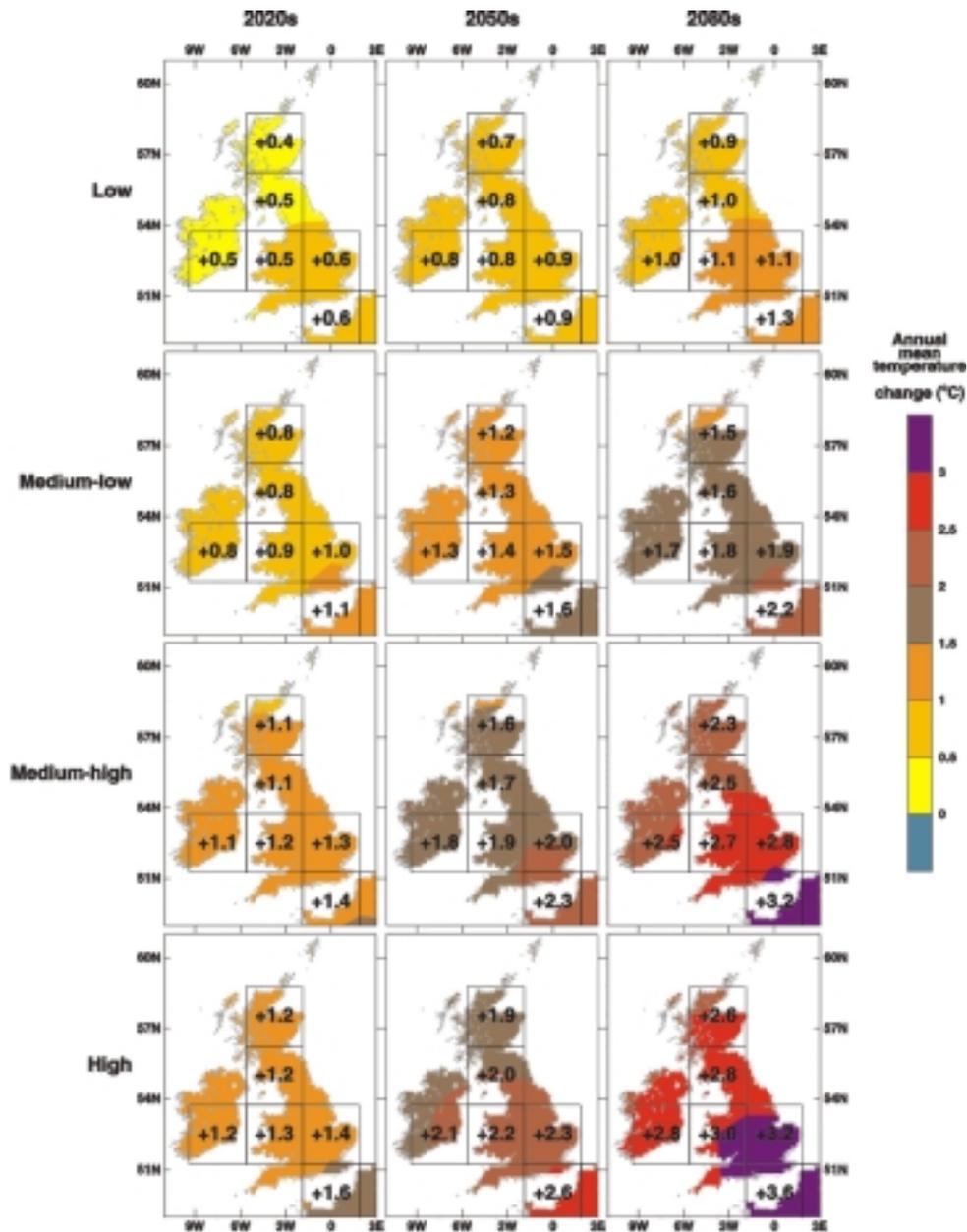


Figure 1.2a Change in mean annual mean temperature (with respect to the 1961-90 mean) for thirty-year periods centred on the 2020s, 2050s and 2080s and for the four UKCIP98 scenarios. Top: **Low** scenario, changes are scaled from the HadCM2 GGd ensemble-mean. Second row: **Medium-low** scenario, changes are from the HadCM2 GGd ensemble-mean. Third row: **Medium-high** scenario, changes are from the HadCM2 GGa ensemble-mean. Bottom: **High** scenario, changes are scaled from the HadCM2 GGa ensemble-mean.

Table 1.2b: A summary of the variables and analyses provided in the UKCIP98 scenarios

| | Variables/Analysis |
|---------------------------------|---|
| Natural climate variability | Mean temperature Precipitation |
| CO ₂ concentration | Average level |
| Sea-level | Change in global-mean and illustration of changing high-tide return periods |
| Mean seasonal climate changes | Mean temperature Precipitation Diurnal temperature range Vapour pressure Mean wind speed Cloud cover Short-wave radiation Potential evapotranspiration |
| Interannual climate variability | Mean temperature Precipitation |
| Accumulated degree days | Mean temperature above 5.5°C Minimum temperature below 0°C Maximum temperature above 25°C |
| Daily return periods | Precipitation Wind speed |
| Airflow regimes | Cyclonicity, direction, strength |
| Gale frequency | Routine, severe and very severe |
| Lightening | Semi-qualitative discussion |
| Downscaling | Discussion |
| Non-linear changes | Qualitative discussion |

- *Natural climate variability:* Climate varies naturally for a range of reasons and these natural variations will remain important to assimilate into climate scenarios. In the future, longer climate model simulations and larger ensembles of simulations should allow better quantification of natural climate variability.
- *Different responses between different global climate models:* The prospect of these differences being narrowed in the short-term is not high. Fundamentally, there remains the range of values for the climate sensitivity that different global climate models yield. The current generation of GCMs yields a range of values between 2.3°C and 4.3°C for a doubling of CO₂ concentrations, but the IPCC Third Assessment Report is quite likely to report the same range as used in earlier assessments, namely 1.5°C to 4.5°C. In addition to such differences in *global* response, GCM experiments continue to yield different *regional* climate change responses. Although there is emerging consistency between *some* GCMs for *some* regions, uncertainties about future climate from this source will remain for the foreseeable future.
- *Poorly resolved regional and local climate changes:* Obtaining descriptions of future climate at higher spatial resolution will continue to be an active area of research. Advances in computing capacity will assist the design and use of higher resolution climate models. These models will almost certainly yield scenario information with greater precision. The UKCIP2001 scenarios will be designed around regional climate model experiments at 50km resolution. But improved *precision* is not the same as improved *accuracy*, and the accuracy of high resolution climate scenarios will continue to depend upon the accuracy of the parent GCMs. Indeed, we may well go through a stage where improved spatial resolution in scenarios will *increase* uncertainty, since there are a number of different methods for regionalising and localising information

from GCMs and as yet we do not know which of these are the most robust.

- *The possibility of abrupt, non-linear changes in the climate system:* Identifying the conditions under which abrupt changes in the climate system may occur will be a major challenge for climate science in the next decade. Some progress may be made, using diverse approaches to risk assessment, but it remains unclear whether our knowledge will advance quickly enough to offer the prospect for robust quantification of such low probability, high impact climate change outcomes.

1.2.2 Socio-economic scenarios

Climate variability and change will certainly not occur in isolation of social and economic change. The consequences of changing climatic conditions will be determined to a considerable extent by the nature of the economic, social and technological domain in which those impacts occur. It is thus essential to develop a view of the world in which future climate changes will be felt. That future world may be very different from today's world. The nature of climate impacts, and our capacity to respond to them, may also be very different.

If the future society holds values which have created a strong system of environmental protection, it will have resilience to the impacts of climate change. It might be argued that a society with a vibrant economy could be resilient to climate change impacts as resources may be available to respond to the impacts. Conversely, if there is neither the will nor resources to put flood protection measures in place, climate change could have a greater effect. The location and size of settlements will also determine the extent of impacts. Clearly, there is a multitude of possible technological, economic, social and political futures. As with the climate change scenarios, socio-economic futures are needed which ensure all possible future conditions are considered.

DETR therefore commissioned the Science Policy Research Unit (SPRU) at the University of Sussex to develop a range of socio-

economic scenarios to support UKCIP. The work builds on that of the IPCC's Third Assessment Report, and on the futures scoping study by the Office of Science and Technology's Natural Resources and Environment Foresight Panel. The SPRU study breaks new ground as it identifies the critical range of parameters for impacts assessment. Four scenarios have been developed: National Enterprise, Local Stewardship, World Markets and Global Sustainability (Berkhout *et al.*, 1999) (see Figure 1.2b). Together with the UKCIP98 climate change scenarios, the socio-economic scenarios will create the underlying framework for integrating results of regional and sectoral studies into a national assessment.

As the main effort of the research team in developing the scenarios focussed on the national level, the regional characterisation of the scenarios was not fully developed. Additional work is underway to enhance the regional application of these scenarios. A workshop was held in February 2000 to consider experience gained from applying the scenarios in the scoping studies of the North West of England (Shackley *et al.*, 1998), Wales (Farrar *et al.*, in press) and the South East of England (Wade *et al.*, 1999). Results from this next stage of the work will enable guidance on the application of scenarios at a sub-UK level to be presented alongside the national scenarios. This work will be published in a forthcoming UKCIP Technical Report.

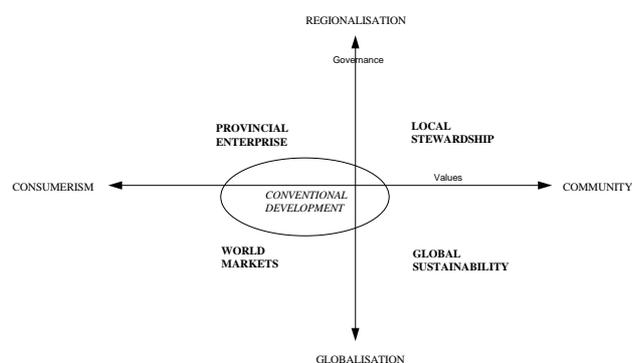


Figure 1.2b: The conceptual framework of the four national non-climate scenarios developed by Berkhout *et al.*, 1999, following developmental work for the IPCC SRES (Davis *et al.*, 1998).

1.2.3 Combining climate and non-climate scenarios

Integrated assessment of climate change needs *consistent* descriptions of both climate and non-climate (socio-economic) futures. Consistency is important because climate and society are co-evolving systems, each influencing the other, at least to some extent. Thus a future world in which social, political and technological changes are ones that lead to a reduction in carbon emissions is not consistent with a climate scenario that assumes accelerating growth in greenhouse gas emissions and therefore a high rate of climate change. Conversely, a climate scenario with a low rate of climate change is not likely to be consistent with a future world which continues its reliance on carbon-based fuels, pays little attention to energy efficiency concerns, and in which there are no agreements to control greenhouse gas emissions.

Consistency between climate and socio-economic futures is therefore clearly desirable, but has not always been achieved in past impacts and adaptation assessments. Full consistency has also not been achieved within UKCIP studies to date. The reasons for this, some suggestions about how to minimise inconsistencies, and what is planned for the next set of UKCIP2001 climate scenarios are summarised below.

The UKCIP98 climate scenarios were commissioned at the beginning of 1998. At that time nearly all the global climate model experiments had been performed assuming a future growth in greenhouse gas concentrations of 1 per cent per annum. The Hadley Centre, whose model was to be used for the UKCIP98 scenarios, had in fact also completed an experiment assuming a growth rate of only 0.5 per cent annum. These two Hadley experiments therefore assumed two different worlds - a medium-high emissions growth rate similar to the IPCC IS92a scenario and a low emissions growth rate similar to the IPCC IS92d scenario. The UKCIP98 climate scenarios were designed around these two experiments and these two future worlds - **High** and **Medium-high** assuming IS92a and **Medium-Low** and **Low** assuming IS92d.

The UKCIP socio-economic futures study began after the climate scenarios had been published. By then it was clear that the old IPCC IS92 emission scenarios were being superseded by the new emission scenarios being prepared for the Third IPCC Assessment. The new emission scenarios will be published in the Special Report on Emissions Scenarios (SRES, to be published June 2000). The SRES scenarios have the potential for much richer descriptions of alternative future worlds, descriptions that could in principle be interpreted at a national level. They are going to be widely publicised and used by the IPCC and other assessment teams over the years to come. Therefore, the UKCIP socio-economic futures were designed around four SRES emissions scenarios, A1, A2, B1 and B2. This timing of events has meant, however, that it has not been possible in the Programme to make a precise match between the climate and non-climate futures.

This inconsistency will be rectified when the new UKCIP2001 climate scenarios are produced. There are now global and regional climate model experiments being conducted, by the Hadley Centre and others, assuming emissions generated by the various SRES worlds. The results of these new experiments will form the basis of the new climate scenarios, so a direct and consistent link with the UKCIP socio-economic futures can be made.

As an interim measure, however, how should the existing four UKCIP98 climate scenarios be combined with the four non-climate futures? At first glance there are 16 possible combinations of scenarios (see Table 1.2c).

There are two ways to decide which combinations should be evaluated, assuming that all 16 are too many to handle. First is to approach the problem from a sensitivity analysis perspective. The extreme combinations can be chosen, to examine how sensitive the UK is to different assumptions about future climate and future socio-economic change. Thus the four combinations marked 'S' in Table 1.2c might be used. This approach would for example examine the impact of a slow rate of climate change in a world of global regulation, environmental awareness and efficient energy use (Global

Sustainability) versus a ‘selfish’ world of inefficient technologies, little environmental concern and parochial markets (National Enterprise). This approach would also examine the impact of both a slow (**Low**) and a rapid (**High**) climate change in a National Enterprise world.

An alternative approach to combining scenarios is to judge which combinations *a priori* are sensible. In this approach the underlying global emissions for each non-climate future are considered and related to the rate of global warming in each climate scenario. Thus a Global Sustainability world is likely to generate the lowest emissions growth and therefore could be considered with the **Low** climate scenario. For the World Markets future, a wide range of global emissions curves are possible since a large diversity of energy technology futures - from heavy fossil use to heavy renewable use - are consistent with the underlying drivers. In this case, all four climate scenarios might be considered. Possible consistent combinations are marked by ‘C’ in Table 1.2c.

There is clearly no single ‘right’ answer to the question of combining the UKCIP climate and non-climate scenarios. As with most scenario analysis, what is important is an explanation of the choices made and a careful interpretation of results.

1.2.4 Report on risk and uncertainty in decision-making

The EA, UKCIP and DETR are developing a Technical Report that will provide guidance to decision-makers on dealing with risk and uncertainty in decision-making. The report will look at climate scenarios, major infrastructure investment decisions and the process of planning for adaptation to climate change. Case Studies are being used to illustrate the integrated use of the assessment tools and techniques. These are being conducted in a number of topic areas including: water resources, the Thames Barrier, coastal and fluvial flooding and strategic forestry planning.

The report will provide decision-makers with guidance on:

- how to recognise where they need to consider the possible consequences of climate change for their decisions;
- the nature of the risks and opportunities posed by climate change, and their associated uncertainties;
- organising this information alongside other information on non-climate risk and uncertainties;
- criteria and frameworks for decision-making on climate change adaptation strategies and the implications of these for climate-sensitive decisions.

The report will be published as a UKCIP Technical Report in early 2001.

Table 1.2c: An approach towards combining the UKCIP climate and non-climate scenarios, developed in consultation with the REGIS study. ‘S’ may be combinations used in sensitivity analysis; ‘C’ may be combinations used if consistency between scenarios is considered.

| | Global Sustainability | | Local Stewardship | World Markets | National Enterprise | |
|--------------------|-----------------------|---|-------------------|---------------|---------------------|---|
| Low | S | C | | C | S | |
| Medium-low | | | C | C | | |
| Medium-high | | | C | C | | |
| High | S | | | C | S | C |

1.2.5 Report on costing the impacts of climate change

DETR are funding the development of a methodology for studies within UKCIP for costing the potential impacts of climate change in the UK.

The research will cover:

- The identification and selection of suitable techniques and mechanisms for costing the impacts of and adaptation to climate change on all relevant sectors, including: the coastal zone; water supply and management; agriculture, forestry and land use; energy; insurance and finance; the natural environment and biodiversity.
- To review how these techniques and mechanisms have already been used in the UK.
- To develop non-monetary ways of evaluating the damages and impacts on habitats and biodiversity etc.
- To assess the suitability of the selected approaches with a range of stakeholders.
- To apply the methodology to cost the potential impacts of climate change on a range of examples drawn from key sectors for the 2020s and 2050s (using the UKCIP98 climate scenarios and with reference to the UKCIP socio-economic scenarios).

1.3 Providing access to information and data

1.3.1 Overview

A central strategy to facilitate integration both within and across modular studies is the use of common data-sets. A key role of the UKCIP is thus to compile and facilitate access to critical data-sets for climate impacts assessment. A multi-disciplinary approach is required to conduct an integrated climate impacts assessment. It is therefore necessary to acquire,

manipulate and integrate many diverse data types to investigate the critical cross-sectoral issues. The necessary data are dispersed over many data providers with which liaison is required to acquire the relevant data. This process can prove challenging because organisations have different licensing structures, sampling strategies, database structures, file formats, geo-referencing and distribution mechanisms.

1.3.2 Data integration: the UKCIP Geographical Information System (GIS)

Key data-sets are being compiled in a Geographical Information System (GIS) for use in UKCIP modular studies. A GIS essentially links together a spatial database with a user-interface that allows the data to be queried and analysed to answer specific questions on its content. By integrating the data-sets in a GIS, it becomes much easier to manipulate data at different scales and handle the diverse formats that they are originally supplied in. It is therefore possible to move between the national UK dimension and more specific local data-sets in the same system, allowing the information to be visualised in different spatial contexts.

Typically, information from the spatial database is visualised in the form of a map, constructed by assembling together layers of thematic data (e.g. soils, vegetation, roads, rivers etc.) relevant to the problem being investigated. The map is therefore customised for a particular purpose. By linking different data-sets with a common geo-referencing system (i.e. the National Grid in Great Britain), possible correlation between themes can be visualised and analysed further. By coupling a modelling approach with the spatial database capabilities of the GIS, a powerful analysis and visualisation system can be developed for impact studies.

The GIS is being developed in an on-going way, reflecting the data requirements of new and current studies. Its application is fundamental to promoting the integration and visualisation of study results. Two of the UKCIP projects, REGIS and MONARCH, are already undertaking data-intensive quantitative

modelling, and are identifying significant issues that will no doubt recur in future studies. Issues include locating and acquiring relevant source data, integrating diverse data-sets in a unified model, transferring data between models, and data confidentiality. In the context of modelling, ensuring data quality and integrity is essential. This necessitates awareness of the sampling strategy and any other assumptions made when the source data were collected. These factors will be propagated through the model and without due caution can create errors in interpretation of the final results.

The UKCIP GIS is being used to assist projects by assembling and validating the data after they have been acquired, which allows the project team to receive the data in the format necessary for their modelling work.

Typically this process becomes a continuum, because, as the project progresses, data at a different scale or in another format are often required for further analysis. The integration of data-sets within a common database is not generally a straightforward process because of the variety of formats the data are received in. For example, some organisations supply files with data beginning in the north west (NW) corner, whereas others use the south west (SW) corner: in such cases, conversion to a common format is not then a trivial problem if the study areas are irregular (as with REGIS). The REGIS study also required all data-sets to be interpolated and co-registered to the same 5km grid, which required considerable programming to be applied. Such problems are magnified further at the UK scale, because devolution has frequently meant that the different regional / national agencies responsible for data have followed a different strategy (e.g. soil survey and conservation bodies). This means that for a project covering all the UK, such as MONARCH, considerable data processing can be involved even before the task of integration.

1.3.3 Key data-sets acquired by UKCIP

A steady flow of data to the UKCIP quantitative projects has been initiated recently. This has allowed certain core data-

sets to be already identified as having high significance for climate change impacts research (in addition to the actual climatological data, of course). These include (see Appendix 1 for details):

- Soils
- Land cover
- Designated sites
- Topographic data
- Administrative and socio-economic data

1.3.4 New developments in data

The most important new sources of data becoming available now are those provided by remote sensing instruments, whether located on satellite or aircraft. This is allowing data to be obtained over large areas at increasingly finer spatial and temporal resolutions, whereas previously a ground survey could only provide a small fraction of this. However, representative sample data on the ground are still critically important so that the remotely-sensed data can be related to the particular features it is intended to classify. This ground-truthing is also important to correct for other possible sources of misclassification, such as radiometric and geometric transformation errors. With these provisos borne in mind, the potential of remote sensing for detecting and monitoring change in the landscape, is very high. Particular developments that are, or will be, highly relevant to UKCIP studies are outlined below and discussed in Appendix 1:

- LIDAR (Light Detection and Ranging)
- Synthetic Aperture Radar (SAR)
- Bathymetry data

1.3.5 Data liability and confidentiality

Legal and other constraints have to be considered when publicising sensitive information based on highly accurate localised data. Copyright and intellectual property right issues occur with the use of most data-sets. Some data providers are very wary of their legal liability as they may have limited control over the way in which data are utilised by end-users. Although most researchers appreciate that the source data may not be completely

accurate, some stakeholders may not appreciate these limitations, and treat a resulting line on a map as an exact boundary.

Conflicts that have arisen between the Data Protection Act and the possible detrimental effect on property values of impact studies have shown the need for a full clarification of the legal situation. It is likely that confidentiality issues will assume a higher profile as more detailed data-sets become available, and the potential to derive more precise results increases. Wider dissemination of key information, such as publication on the Internet, is often delayed by such concerns (as encountered by the Environment Agency's Indicative Floodplain Map of England and Wales, and the Contaminated Lands Register). With new satellites providing data at resolutions of 1m/pixel, or even greater levels of detail in future, this is a general issue for many facets of society. It will become a recurrent issue for UKCIP as the focus shifts towards increasingly detailed studies where potential change is most pronounced (see Chapter 5).

1.4 Conclusions

This chapter has described the aims and framework of the UK Climate Impacts Programme, and set out the framework and approach through which its aims are being realised. Highlights of achievements in the first three years of the UKCIP are listed below:

- UKCIP has brought together organisations that would not have normally have worked together;
- Networks of ‘users’ and ‘providers’ have been created;
- A wide range of stakeholders has become involved in studies – this is the first step in engaging stakeholders in climate change impacts research and raising awareness of the need to adapt to these impacts;
- Awareness amongst stakeholders of climate change impacts has been raised
- UKCIP’s approach has enabled stakeholders to define the research agenda, and so linked research to stakeholders’ needs;
- A range of substantial scientific studies have been initiated;
- A host of routes to operationalising stakeholder engagement have been developed;
- UKCIP studies have brought into focus the need for a ‘new way of thinking’ across organisations and sectors;
- Critical gaps in our understanding that need addressing have been identified;
- Barriers to getting further research done have been identified;
- New climate change and socio-economic scenarios have been developed for the UK. The climate change scenarios have been widely used in the UK.

1.5 References

CCIRG (1996) *Review of the Potential Effects of Climate Change on the United Kingdom*. HMSO, London.

Berkhout, F., Hertin, J., Lorenzoni, I., Jordan, A., Turner, K., O’Riordan, T., Cobb, D., Ledoux, L., Tinch, R., Hulme, M., Palutikof, J and Skea, J. (1999) *Socio-economic future scenarios for climate impacts assessment*. SPRU, University of Sussex, Brighton. 81pp.

Davis, G. *et al.* (1998) *IS99 Storylines and Scenarios*. Zero Order Draft Paper for the IPCC Special Report on Emissions Scenarios. Environment Agency (2000). *Climate Adaptation, Risk and Uncertainty Decision Framework Interim Report*. Report No. 21, National Centre for Risk Analysis and Options Appraisal, Steel House, London.

Farrar, J., Vaze, P., Hulme, M. and Reynolds, B. 2000. *Wales: Changing Climate, Challenging Choices. A scoping study of climate change impacts in Wales*. Report prepared for the National Assembly of Wales. In press.

SPA and ESYS (1996). (Science and Policy Associates Inc. and ESYS Ltd.) *Proposal for a UK Integrated Climate Change Impacts Assessment*. Report prepared for the Department of the Environment and the Environment Agency. Department of the Environment, London. 28pp.

Shackley, S., Wood, R. Hornung, M. Hulme, M., Handley, J. Darier, E. and Walsh, M. 1998. *Changing by Degrees - The Impacts of Climate Change in the North West of England: Technical Overview*. University of Manchester, Manchester. 63pp.

Wade, S., Hossell, J. and Hough, M. (Eds.) 1999. *The Impacts of Climate Change in the South East: Technical Report*, WS Atkins, Epsom, 100pp.

Annex 1.1: List of publications produced in the first three years of UKCIP

Berkhout, F., Hertin, J., Lorenzoni, I., Jordan, A., Turner, K., O’Riordan, T., Cobb, D., Ledoux, L., Tinch, R., Hulme, M., Palutikof, J and Skea, J. (1999) *Socio-economic future scenarios for climate impacts assessment*. SPRU, University of Sussex, Brighton.

Farrar, J., Vaze, P. , Hulme, M. and Reynolds, B., (2000). *Changing Climate Challenging Choices: The impacts of climate change in Wales from now to 2080 – Technical Report*. The National Assembly for Wales, Cardiff.

Hulme, M. and Jenkins, G. 1998. *Climate Change Scenarios for the United Kingdom - Summary Report. UK Climate Impacts Programme Technical Report No.1*. Climatic Research Unit, Norwich. 16pp.

Hulme, M. and Jenkins, G. 1998. *Climate Change Scenarios for the United Kingdom - Scientific Report: UK Climate Impacts Programme Technical Report No.1*. Climatic Research Unit, Norwich. 61pp

Kerr, A., Shackley, S., Milne, R. and Allen, A. 1999. *Climate Change: Scottish Implications Scoping Study*. Scottish Executive Central Research Unit, Edinburgh. 75pp.

National Assembly for Wales, 2000. *Changing Climate Challenging Choices: The impacts of climate change in Wales from now to 2080 - Summary Report*. The National Assembly for Wales, Cardiff. 10pp.

Shackley, S., Wood, R. Hornung, M., Hulme, M., Handley, J., Darier, E. and Walsh, M. 1998. *Changing by Degrees - The Impacts of Climate Change in the North West of England: Technical Overview*. University of Manchester, Manchester. 63pp.

Sustainability North West, 1998. *Everybody has an Impact - Climate Change impacts in the North West of England: Summary Report*, Sustainability North West, Manchester. 13pp.

UK Climate Impacts Programme, 1998. *Climate Change Impacts in the UK - The agenda for assessment and action*. Department of the Environment, Transport and the Regions, London. 17pp.

Wade, S., Hossell, J. and Hough, M. (Eds.) 1999. *The Impacts of Climate Change in the South East: Technical Report*, WS Atkins, Epsom, 100pp.

WS Atkins, ADAS and the Met. Office. 1999. *Rising to the Challenge - Impacts of Climate Change in the South East in the 21st Century: Summary Report*. WS Atkins, Epsom. 15pp.

Annex 1.2: Background information on UKCIP

A1.2.1 Organisations involved in UKCIP project steering committees

Table A1.2a: UKCIP project steering committees

| Study | Project Steering Committee |
|----------------------------------|---|
| Scotland scoping study | Scotland Executive, COSLA, DETR Global Atmosphere Division, Scotland Environmental Protection Agency |
| Wales scoping study | CLA/Farmers Union, Countryside Council for Wales, Environment Agency, Forestry Commission, National Assembly for Wales, UKCIP, University of Wales, Wales Tourist Board, Wales Wildlife Link, Wales Local Government Association, Wales Water, Wales Development Agency |
| North West England scoping study | AXA Insurance, Environment Agency, Government Office for the North West, National Trust, North West England Regional Association, North West Water, Sustainability North West |
| South East England scoping study | Country Life Magazine, Environment Agency, Government Office for the South East, Hampshire County Council, Kent County Council, National Trust, Surrey County Council, Thames Water, West Sussex County Council, WWF-UK |
| South West England scoping study | Cornwall College, Cornwall County Council, Cornwall Enterprise Ltd, Deborah Clark consultancy, Environment Agency, Government Office for the South West, National Trust, Plymouth Marine Laboratory, Universities of Exeter & Plymouth, West Country Tourist Board, Westcountry Television |
| DETR / MAFF Biodiversity review | DETR Wildlife and Countryside Directorate, MAFF Conservation and Management Division, National Assembly for Wales, English Nature, Scottish Natural Heritage, Countryside Council for Wales, Environment Agency |
| REGIS project | MAFF (CSG, FCD and RME), DETR Wildlife and Countryside Directorate, UKWIR, Environment Agency and English Nature |
| MONARCH project | English Nature, Countryside Council for Wales, Environment Agency, Environment and Heritage Service (Northern Ireland), Dúchas The Heritage Service, National Parks and Wildlife (Republic of Ireland), National Trust, National Trust for Scotland, Royal Society for the Protection of Birds, Scotland Natural Heritage, WWF – UK |
| Health review | Department of Health |

Table A1.2b: Attendance at the launches of UKCIP study results

| Launch event | Number of invited attendees present |
|--------------------|-------------------------------------|
| Climate scenarios | 95 |
| Scotland | 200 |
| Wales | 135 |
| North West England | 250 |
| South East England | 270 |
| South West England | 150 |

A1.2.2 Funding of UKCIP studies

Significant contributors for studies have come from central government where UKCIP has proved to be an effective vehicle to lever involvement of a wider range of departments (see Box A1.2a). Private industry's involvement so far is limited, largely to the water and insurance sectors. The sums needed for involvement in scoping studies have not necessarily been large, for example in the South East England scoping study contributions of £2,000 to £5,000 led to a total of £40,000 being raised, including £3,000 from Country Life magazine. More difficulties arise

in raising funds for fundamental research. Outside the Governmental sector a notable contribution has been made by UKWIR (the research arm of the UK water industry) of £50,000 to the REGIS study (Sections 1.1.3 and 3.2). The budget for the Programme Office was £850,000 over the 1997-2000 period and so far £840,000 has been raised for projects including £150,000 from private industry and £150,000 from non-central Government.

Researchers involved in UKCIP studies to date are summarised in Box A1.2b.

Box A1.2a: Funders of UKCIP studies and initiatives so far

Scottish Executive, National Assembly for Wales, Northern Ireland Environment and Heritage Service, Acordis, Arkleton Trust, Association of British Insurers, AXA Insurance, Blaby District Council, Boston District Council, Carlton TV, CCMS - Plymouth Marine Laboratory, Cheshire County Council, Cornwall County Council, Country Life Magazine, Countryside Agency, Countryside Council for Wales, Department of Health, DETR Wildlife and Countryside Directorate, Derbyshire County Council, Dúchas The Heritage Service, National Parks and Wildlife (Republic of Ireland), Duchy of Cornwall, East Midlands Airport, East Midlands Link, English Nature, Environment Agency, Government Offices for the East Midlands, North West England, South East England, South West England and West Midlands, Hampshire County Council, Kent County Council, Lancashire County Council, Leicestershire County Council, MAFF, Manchester Airport, Marsh UK Ltd, Midlands Environmental Business Club, The National Trust, The National Trust for Scotland, NatWest Bank, North West Regional Association, North West Regional Chamber, North West Water, Northamptonshire County Council, Nottinghamshire County Council, Peak District National Park, PROSPER, Rolls Royce plc, The Royal Horticultural Society, Royal Society for the Protection of Birds, Scottish Natural Heritage, Severn Trent Water Company, South West Water, Surrey County Council, Surrey Wildlife Trust, Sustainability North West England, SWEB, SWEL, Tarmac plc, Thames Water, The Royal Horticultural Society, Toyota UK, TXU-Europe, UKWIR, University of Exeter, University of Plymouth, Wessex Water, West Sussex County Council, Westcountry Television, Westcountry Tourist Board, Wilkinsons and WWF-UK.

Box A1.2b: Researchers involved in UKCIP studies to date.

ADAS, Cranfield University, ECOTEC Research and Consulting Ltd, ERM, Institute of Terrestrial Ecology, Komex Clarke Bond, Lancaster University, Metroeconomica Ltd., Middlesex University, Risk and Policy Analysts Ltd., RSPB, Silsoe Research Centre, The Met. Office, The University of Edinburgh, The University of Manchester, UMIST, Université catholique de Louvain, University of Durham, University of East Anglia, University of Newcastle, University of Oxford, University of Sussex, University of Wales, Bangor, WS Atkins, WWF-UK

A1.2.3 Early stages of the Programme

Critical aspects of the approach, structure and work of UKCIP were determined through a scoping study funded by Global Atmosphere Division (GAD) of the then Department of the Environment (DoE) and the Environment Agency, which involved Canadian and US-based scientists (Science Policy Associates and ESYS, 1996).

A considerable amount of climate change impacts research had been conducted in the UK prior to 1996. But much of this research focused on individual sectors or specific regions of the UK. A critical gap was seen to be emerging, namely the need for cross-sectoral impacts studies that provided decision-makers with information they needed, rather than what researchers thought might be useful.

The scoping study commissioned by the DoE recognised that successful integrated assessments should be based on “sound science using the best available information” and should be “credible for policy makers through establishing an open process involving potential stakeholders to ensure the assessment addresses their needs” (SPA and ESYS, 1996 p.ii).

It was proposed that aims for a UK-wide assessment should be to:

- provide information on climate change impacts to stakeholders for decision-making;
- provide relevant output to stakeholders and connections to other sectors for integration;
- act as a demonstration study.

The scope of the proposed Programme was to:

- have a national perspective with nested studies at different geographical scales;
- examine significant sectors of interest initially, extending to all sectors where possible, using a screening process with stakeholders to identify key priorities on which to focus efforts;
- build on existing information and studies where possible.

Extensive stakeholder consultation and a two day workshop tested the emerging ideas. The moment seemed right to try a cross-cutting, integrated approach led by stakeholders, following on from the second report of the UK Climate Change Impacts Review Group published in 1996 (CCIRG, 1996). (This was a sectoral assessment by experts, based on the outputs of the Hadley Centre’s HadCM1 climate model). In April 1997, UKCIP was established.

The first study to get underway was in the North West of England. A key player was the former County Planning Officer for Lancashire County Council⁵, who convened a regional workshop in October 1997 in Oldham. Great interest was stimulated by this event within the region. UKCIP was able to suggest that a scoping study be started. North West England subsequently became the second region (the upland dimension), to be included in the REGIS project with East Anglia. Existing strong regional associations facilitated these developments. Particular momentum was gained when the issue was taken on by a regional organisation, Sustainability North West (SNW).

Momentum in the Programme accelerated in 1999 (see Table A1.2c for a sequence of significant events within the Programme), following the publication of the UKCIP climate scenarios in October 1998 (see Section 1.2), and as a result of the work in North West England. A key next step was a workshop, convened by the Scottish Executive⁶ in September 1998, and supported by the Programme Office team, which stimulated the undertaking of a scoping study in Scotland.

⁵ Graeme Bell, now at the Town and Country Planning Association

⁶ Then The Scottish Office

Table A1.2c: Significant events within the first three years of UKCIP

| | DATE | EVENT |
|--------------|--|--|
| 1996 | 12-13 March | SPA and ESYS host expert workshop on behalf of the then DoE and National Rivers Authority to consider the framework, resourcing and management of an integrated climate impacts assessment in the UK |
| | Autumn | DoE and the Environment Agency publish a proposal for a UK Integrated Climate Change Impacts Assessment |
| 1997 | March | Tenders invited to conduct a UK-wide assessment |
| | April | DETR award contract for the first three years of UKCIP to the then Environmental Change Unit (ECU), University of Oxford and ERM. |
| | 15-16 July | First workshop of key stakeholders held at Wadham College, Oxford |
| | October | Initial core team recruitment completed |
| | October | First regional workshop convened by the North West Regional Association First scoping study started, commissioned by the North West Climate Group and managed by Sustainability North West |
| 1998 | March | UKCIP Steering Committee convened |
| | 5 June | Climate Change Impacts in the UK: The Agenda for Action and Assessment launched at DETR, Eland House on World Environment Day |
| | 14 September | The Scottish Office / UKCIP workshop on climate change impacts in Scotland |
| | 23 September | First meeting with countryside agencies and NGOs to develop concept for MONARCH project |
| | 16 October | Launch of the UKCIP98 climate change scenarios at DETR, Eland House, London |
| 11 December | Ministerial launch of North West England scoping study at Manchester Airport | |
| End December | REGIS project commissioned by MAFF, UKWIR and DETR | |
| 1999 | Mid January | DETR Biodiversity Review study commissioned by DETR Wildlife and Countryside Directorate and MAFF |
| | February | MONARCH project commissioned by English Nature and seven partners |
| | 18 February | Department of Health Expert Review begins |
| | 19 February | First meeting of South East England scoping study Steering Committee |
| | 19 April | REGIS stakeholder workshop, Preston |
| | 22 April | Socio-economic scenarios workshop, DETR |
| | 27 April | REGIS stakeholder workshop, Carlisle |
| | 18 May | CBI briefing on scenarios |
| | 18 June | REGIS workshop, Bury St. Edmunds |
| | 30 June | DETR Biodiversity Review study, Workshop I |
| | 9 July | UKCIP convenes Research Forum – the first meeting of research teams and funders on all UKCIP studies, Linacre College, Oxford |
| | 15 September | DETR Biodiversity Review study, Workshop II |
| | 28-29 October | The Climatic Challenge Conference, St Mellion |
| 25 November | Ministerial launch of South East England scoping study, Royal Geographical Society, London | |
| 3 December | Ministerial launch of Scotland scoping study, The Scottish Executive, Edinburgh | |
| 2000 | January | East Midlands scoping study begins |
| | 11 February | Study on risk and uncertainty in decision making begins |
| | 11 February | Study to develop a methodology to cost climate change impacts begins |
| | 18 February | Launch of Wales scoping study, Welsh Assembly, Cardiff |
| | 23 February | Regional socio-economic scenarios workshop held, Linacre College, Oxford |

Chapter 2

Results from Sub-UK Scoping Studies

Introduction

2.1 Scotland scoping study

Andrew Kerr

2.2 Wales scoping study

John F. Farrar

2.3 Climate change impacts in North West England

Simon J. Shackley

2.4 The South East England scoping study

Steven Wade, Jo Hossell and Malcolm Hough

2.5 South West England

Kylie J. Russell

Introduction

Scoping studies have been commissioned by the Scottish Executive, National Assembly for Wales and regional groups in England to understand the impacts of climate change on their area and consider adaptation responses. So far (March 2000) scoping studies on the impacts of climate change have been completed in Scotland, Wales, the North West and the South East of England (see Figure 2a). A scoping study on impacts in the East Midlands is underway, and studies are at inception in the West Midlands and Northern Ireland. A major 2 day conference was held in the South West of England in October 1999, in response to the recognised need for the region to develop a better understanding of climate change impacts. A formal scoping study was not undertaken in this region but preparatory work for the conference and focused discussion in workshops enabled significant material for the region to be assembled.

This section presents contributions on completed studies from the project team members who undertook them. The teams were asked to provide information from their studies on the following:

- main findings on vulnerability;
- key issues;
- use of the UKCIP framework (including climate and non-climate scenarios and technical support);
- institutional structure for the study;
- main recommendations for responses and adaptation; and
- future research priorities.

While most of the studies focussed on the impacts of climate change and adaptation, the Scotland study also addressed mitigation issues.

The information presented in the studies was collected mainly by literature review, use of expert judgement and interviews with key stakeholders. Stakeholders vary considerably in their knowledge of climate change impacts, and it should be noted that there may be new and ongoing programmes of policy development, data collection and review that the study authors did not consider.

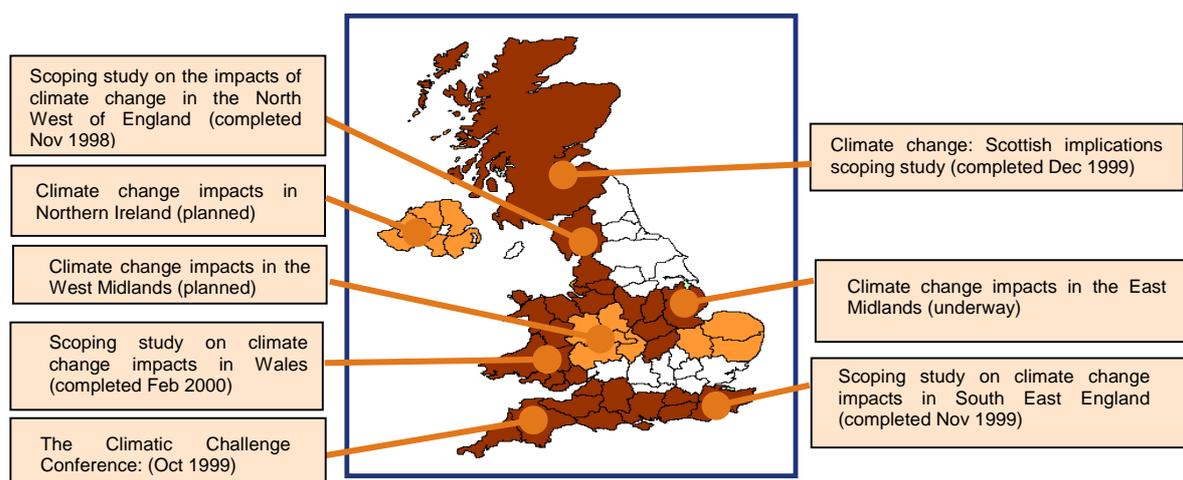


Figure 2a Map of regional studies planned, underway or completed in the UK Climate Impacts Programme.

2.1 Scotland scoping study¹

Andrew Kerr²

2.1.1 Vulnerability: main findings

Climate change issues

Climate change will have both direct and indirect impacts on Scotland. The direct impacts of climate change reflect changes in the physical environment that affect society or the cost of adapting to this change. The indirect impacts result from the cost of minimising the emissions of greenhouse gases, which are the prime human influence on global climate.

Over the next century, it is likely that Scotland will become warmer; sea levels, average rainfall and the frequency of intense rainfall events will rise with an increased risk of flooding; and the frequency of severe gales may increase (Hulme and Jenkins, 1998). While some changes will be beneficial, many will be detrimental. As well as these national climate impacts, Scotland will be affected by the impact of climate change on other countries.

An alteration in the ocean circulation of the North Atlantic Ocean remains a possibility. This may lead to a very different climate to that described above.

Precipitation

The main detrimental impact of climate change across Scotland is likely to be the change in seasonal and regional patterns of precipitation, in conjunction with more frequent and intense rainfall events. Those most vulnerable to such changes appear to be organisations with responsibilities for maintaining services over a

wide geographical area, such as transport organisations, local authorities and water authorities. Other specific problems arise from worsening public health with increased prevalence of damp in the domestic housing sector and the location of business or domestic infrastructure in areas at risk from river flooding. Redesigning waste and floodwater systems to cope with more intense rainfall events or rising sea level will be expensive and require extensive forward planning. At present, the future climate scenarios cannot shed light on regional variations of precipitation across Scotland.

Sea level

Sea level rise provides few benefits for society or ecosystems, but the impact around Scotland is likely to be more localised than elsewhere in the UK. There are only a few dwellings at risk of the ~0.5m sea level rise projected by 2050, though infrastructure redesign may be required at larger ports and coastal installations to minimise disruption to commercial operation at high tides. On rocky coasts, the impact is likely to be minimal. Soft coasts, comprising sand dunes and estuarine mudflats, may reduce in size or migrate inland if allowed by human activities.

Storms

Evidence suggests that gales have increased in frequency and severity in recent years. No clear picture emerges from the available climate scenarios, though severe gales may increase. Since most sectors are extremely vulnerable to increased frequency of storms, further information is vital.

¹ The Scotland Scoping Study was funded by the Scottish Executive. Study findings are presented in the report: Kerr, A., Shackley, S., Milne, R. and Allen, S. (1999). *Climate Change: Scottish Implications Scoping Study*. HMSO, Edinburgh, 75pp.

² Centre for Environmental Change and Sustainability, University of Edinburgh.

Temperature

Across Scotland, the projected rise in temperature is likely to be more beneficial than detrimental. Reduced energy costs in the business and domestic sectors from a warmer winter should offset the extra costs of additional cooling in summer. There will be less disruption to public services and transport if icing problems are less common. Public health is likely to benefit if the higher temperatures mitigate problems of damp in housing and cold-related winter deaths. Increased use of shared city space in a warmer future will assist the development of sustainable urban areas. Agriculture and forestry benefit from increased rates of growth, though this could be balanced by further migration of pests and disease from the south of Britain. Exceptions occur of course, such as increased photochemical smog in warmer seasons.

Mitigating climate change

Measures to reduce emissions of greenhouse gases include taxation, regulation, emissions trading schemes, financial incentives and voluntary agreements. These measures have a direct impact on key drivers in most sectors, for example tax, energy efficiency and pollution control. While there is little consensus on the appropriate balance between these measures, most respondents favour incentives for influencing individual and organisational behaviour, rather than punitive taxes. The timescale for detrimental physical impacts of climate change in Scotland is generally much longer than the timescale for imposing measures to reduce greenhouse gas emissions. There is, therefore, a distinct gap between the financial impact of emissions reduction strategies and the observance of a changed climate.

2.1.2 Key Issues

Stakeholders

The use of stakeholder interviews is a powerful technique for rapidly assessing the knowledge-base and communicating the primary issues concerning climate change. Its uncertainties and limitations are well known (e.g. Hassol and Katzenberger, 1997). There is a particular difficulty in assessing expert responses

consistently between the various environmental, economic and social sectors.

The success in differentiating the impact of future climate from the impact of future socio-economic change is highly dependent on the knowledge of the individual stakeholder and the context of their sector. For example, respondents in the energy industry had long planning horizons and had considered factors forcing long-term change. Conversely, many respondents from other sectors had shorter planning horizons and had not considered longer-term changes. It is clear that identifying the stakeholder with the most appropriate knowledge is vital. Use of a powerful sponsor, in this case The Scottish Office, provides strong motivation for more senior representation from organisations.

The UKCIP98 climate scenarios

The UKCIP98 climate scenarios were vital for providing a vision of the future. Nevertheless, in practice, the scenarios were described in a highly simplified form because of the limited time available. This discussion usually related to the core elements of temperature, precipitation variation, likely gale frequencies and sea level rise. This limited description of the scenarios emphasised the importance of obtaining a general sensitivity of stakeholders sectors to climate change, before considering their vulnerability to the specific impacts suggested by the UKCIP98 climate scenarios.

Looking to the future

A number of respondents noted that socio-economic change over the next 50 to 100 years will be too great for them to provide any meaningful consideration of how the specified future climate will impact on their sector in the future. For example, many existing businesses will have disappeared over the next 50 years. These respondents reflected that focussing on climate impacts over the next 10 to 30 years would provide a less abstract set of futures that was more appropriate to users.

Scotland: sectoral issues

- The market is the driving force in the energy sector, coupled with tight regulation to protect the public interest. Climate change is one uncertainty of many

in this fast-changing industry. The planning horizon in the industry is well over 20 years, which suggests that the sector is in a good position to develop adaptive strategies as better information on climate impacts becomes available.

- The key drivers of change in the transport sector are for increasing the effectiveness of transport systems and reducing congestion and air pollution. Climate change impacts present an important business risk to the transport sector. The design of transport infrastructure has a long lead-time, which suggests that information on future climate change impacts should be an important element of the planning process.
- Numerous interwoven factors such as poor housing stock, fuel poverty, public health, and energy efficiency will drive change in the domestic sector. Climate change issues are not amongst the key drivers, although housing is particularly vulnerable to increases in rainfall. Future planning of housing could beneficially include an assessment of the climate risks, with closer co-ordination between insurers, planners and the Scottish Environmental Protection Agency (SEPA).
- The key drivers in the public services concern the provision of a diverse range of services to the population under the competing demands of high expectation and tight budgets. Apart from the Water Authorities, climate change issues are not generally a high priority. For local and public health authorities, there are numerous competing claims on resources and existing financial structures militate against a proactive approach to climate change.
- The management of Scotland's natural resources is perhaps the sector most affected by climate change impacts. Forestry is likely to benefit. In agriculture, changes to subsidy will remain more important than direct climate impacts. Fishing and fisheries are likely to be adversely affected; there is compelling evidence that recent declines in both migratory salmon and some marine species may be linked to fundamental changes in ocean circulation around Scotland.

Scotland: business issues

The vulnerabilities of business to climate impacts depend on their specific operation. In general terms, the economy of Scotland (like that of the UK) has moved away from manufacturing and towards services (including retail and finance). The service industry, which contributes nearly two thirds of Scottish GDP (Figure 2.1a) and three quarters of its workforce, is less sensitive than other business operations to the direct impacts of climate change. The key issues for both service and manufacturing business are impacts from extremes of temperature, rainfall and storms on buildings and communication structures.

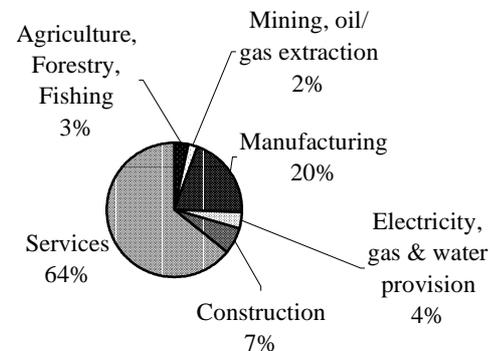


Figure 2.1a. Sectoral contributions to Scottish GDP (1995 figures).

Climate change issues rarely influence business decision-making, which is predominantly driven by the market. Nevertheless, infrastructure will need to be designed to withstand future climate change. Some sectors are likely to be more responsive to climate change than others, particularly if their market sector requires a rapid turnover of product. Compared to many other sectors, respondents felt that most businesses can respond to the impact of climate change flexibly and incrementally. Of far greater concern to the study respondents was the impact of forthcoming climate mitigation measures.

Indirectly, the impacts of climate change might be more significant through changing structures of market demand. People tend to consume different kinds of products in different weather conditions and in different seasons (Palutikof *et al.*, 1997). For instance, more fruit and vegetables are sold in the summer and beer sales rise in hotter weather, whilst clothing and

footwear sales decline during hot dry summers. Such relationships between business operation and climate impacts are highly tentative and disentangling the influence of other socio-economic changes makes identifying causal relationships problematic.

Scotland will also be affected by the impact of climate change on other countries. At present, projections of regional climate change and its resulting impacts are full of uncertainties. This international dimension to climate change provides both business opportunities and potential risks for Scotland.

The insurance industry is one of the few industries with a direct stake in climate change. More weather-related insurance claims could affect the performance of the insurance sector, though yearly adjustments allow rapid response to changed profitability. In addition, the financial sector in Scotland could be affected by the impacts of climate change on investments and insurance claims in other parts of the world.

Other trends in the industry will influence the sector, increasing the significance of climate change. For example, if the move towards more individual accountability observed in car insurance extends to house insurance, it may increase the significance of flood and storm damage risk. This may provide an incentive for more rational planning decisions in the future with respect to development in higher risk areas, but equity issues will certainly arise with respect to the owners of existing property.

2.1.3 Institutional structure

Study objective

Climate Change: Scottish Implications Scoping Study was commissioned by The Scottish Office (now Scottish Executive) to improve the understanding of the implications of climate change in Scotland. The research will inform the policy response to the impacts of climate change and help to identify measures to reduce greenhouse gas emissions from Scotland.

Study team

Andrew Kerr, Simon Shackley, Ronnie Milne, and Simon Allen from the University of Edinburgh, University of Manchester Institute

of Science and Technology (UMIST) and the Institute of Terrestrial Ecology (ITE) respectively conducted the research between December 1998 and July 1999. The work was guided and advised by an Advisory Group comprising members of the Scottish Executive, UKCIP, the Department of Environment, Transport and the Regions (DETR), the Scottish Environmental Protection Agency (SEPA) and the Committee of Scottish Local Authorities (COSLA).

Methods

The study consisted of a literature and policy review and consultation with experts to assess the knowledge of predicted impacts and the mitigation of climate change within their sector. A total of 74 experts were consulted representing six key sectors affected by climate change: energy; business; transport; domestic; public services; and agriculture, forestry and fisheries.

The emphasis of the expert consultation was to obtain the general sensitivity of a particular sector to climate. The specific vulnerability of each sector to future climate was identified using the UKCIP98 climate scenarios (Hulme and Jenkins, 1998).

In order to distinguish future change arising from climate impacts from those arising from the numerous other social and economic pressures, stakeholders were asked to identify the factors that drive change in their sector. These factors were compared with the sensitivity of the sector to climate. This approach provided stakeholders with a means of considering the role of climate change independently of the changing socio-economic pressures on their sector.

Information sources

The prime source of information came from the face-to-face or telephone interviews with the stakeholders, in conjunction with the 1998 UKCIP climate scenarios. The stakeholders comprised members of a wide range of public and private organisations affected by climate change issues. In addition, the reports of two workshops on climate change issues, organised by the (then) Scottish Office in 1998, provided a baseline assessment of climate issues in Scotland and engendered interest amongst a wide constituency of organisations (The Scottish Office and EPSRC Global Environmental

Change Programme, 1998; The Scottish Office and UKCIP, 1998). Other information sources came from Government Department (e.g. DETR, MAFF) or Agency (e.g. SNH, SEPA) reports concerned with climate change issues in particular sectors or regions. In addition, non-governmental organisation and company reports exploring specific aspects of climate change proved a fruitful source.

2.1.4 Response and adaptation: main recommendations

Response to climate change issues

Broad similarities in the response to climate impacts and climate mitigation strategies are apparent across the different sectors. Climate is not the primary driver of change in any sector. The changes outlined by the climate scenarios, though they may pose serious commercial or practical risks to some sectors, are unlikely to change this situation. For many sectors, more specific information is required about climate change impacts before it will influence strategic decisions. In comparison, measures to reduce greenhouse gas emissions have a direct impact on key drivers in most sectors, for example tax, legislation, energy efficiency and pollution control. Implementation of emissions strategies begins in 2001 with the introduction of the climate change levy. The time-scales for detrimental physical impacts in Scotland is generally much longer than this. It becomes clear that there is a distinct gap between the financial impact of emissions reduction strategies and the observance of a changed climate.

This gap between the imminent costs of emission reduction and the much longer-term impacts of climate change could generate difficulties with respect to public perceptions. Shouldering significant cost burdens and implementing behaviour changes well in advance of, or indeed in the absence of, climate change impacts will be a difficult political burden. Therefore, the use of mechanisms to re-cycle revenue within sectors, such as transport, is likely to be increasingly important. Awareness of climate change issues is likely to rise as emissions strategies impact on financial decision-making.

Links between climate change issues

The link between the drivers of change in different sectors, the impacts of climate and forthcoming emission reduction strategies also points to mutually beneficial 'win-win' situations. These occur when the forces driving change in a sector lead to climate adaptation or a reduction in greenhouse gas emissions without imposing impractical costs on the sector. Examples include:

- Improving the quality of housing stock will improve their thermal qualities and state of repair, which both reduces emissions and minimises detrimental impacts of climate change in conjunction with improving health and enhancing social inclusion;
- Solving transport congestion and pollution, by more integrated social and transport planning, reduces emissions and may improve the capacity of the transport system to cope with adverse impacts;
- Growth in the forestry industry provides opportunities for linkages with rural policies on jobs, commercial benefits from biomass fuel and wooden buildings, increased leisure opportunities and opportunities to contribute to Common Agricultural Policy reform, and the potential for carbon sequestration.

Recommendations

The main recommendations from this study concern three broad themes. The first concerns the climate science. Different sectors are sensitive to different elements of climate. Almost without exception, there is a requirement from the various sectors for a more detailed description of regional and seasonal changes in climate across Scotland. This requires further work on producing climate model results at time- and space-scales of relevance to users. At present, the climate variables for which there is least confidence are those of most interest to users. Sectors are particularly vulnerable to extreme events, such as the frequency of intense rainfall events and changes in the frequency of storms. In addition, there is a clear need for more comprehensive observed climate data from Scotland with which to test the climate models and observe ongoing trends. Maps of exposure of different areas to climate impacts such as

increased flooding, sea level rise and storm frequency would be beneficial to local authorities and other organisations for planning responses.

The second recommendation from the study is that the response to climate change requires a cross-cutting approach to climate change issues. This requires the identification of the linkages between the main driving forces of change on each sector, the likely impacts of emissions strategies, and the actual climate impacts. Strategies for reducing greenhouse gas emissions will have a far greater impact on sectors in Scotland over the near to medium future than the direct effect of climate change.

The final implication of this study is that perception of climate change issues varies markedly between organisations and sectors. In view of the financial implications of forthcoming climate mitigation strategies, there is a need for a better understanding of public perceptions of climate change issues. In particular, the public awareness and acceptance of the necessity for the imminent costs of climate mitigation and adaptation to minimise detrimental climate impacts in the future must be appraised.

2.1.5 Future research priorities

Future research priorities reflect the three broad themes of climate science, linkages between climate issues, and understanding public perceptions.

Climate science

- The creation of a ‘metadata’ depository, which identifies climate data held by different organisations, would be a useful tool for climate impact assessments. This information needs to include key indicators of climate that are of interest to users, such as an index of storminess and of rainfall intensity;
- Maps of the exposure of different regions to future climate impacts, such as flooding, storminess and sea-level rise, would assist planners and insurers;
- Information on the changing patterns of precipitation and snowfall across

Scotland along with improved modelling of future changes are vital;

- An analysis of the impact of climate change on the different regions of Scotland is important because of their very different socio-economic and environmental contexts.

Linkages between climate issues

- The effect of climate impacts and mitigation measures on land use strategies, such as afforestation and agricultural policies, should be investigated;
- Research should investigate the links between the likely socio-economic changes in the different sectors, the requirements of that sector to reduce greenhouse gas emissions, and the likely impacts of climate change;
- The raft of business opportunities associated with climate change issues should be explored;
- A comparison of expected climate impacts and planned mitigation and adaptation strategies with countries, such as Norway or Sweden, which have similar socio-economic or environmental contexts to Scotland would provide opportunities for exchanging ideas on best practice.

Public perceptions and awareness of climate issues

- Understanding public perceptions of climate change issues is critical, particularly the awareness and acceptance of measures to reduce greenhouse gas emissions prior to visible signs of detrimental climate impacts.

2.1.6 References

- Hassol, S. and Katzenberger, J. (eds.) 1997. *Elements of Change 1996: Session Two: Characterising and Communicating Scientific Uncertainty*, Aspen Global Change Institute, Aspen.
- Hulme, M. and Jenkins, G. (1998). *Climate Change Scenarios for the United Kingdom*. UKCIP Technical Report No. 1, Climatic Research Unit, Norwich, 80pp.

Kerr, A., Shackley, S., Milne, R. and Allen, S. (1999). *Climate Change: Scottish Implications Scoping Study*. HMSO, Edinburgh, 75pp.

Palutikof, J.P., Subak, S. and Agnew, M.D. (1997) *Economic Impacts of the Hot Summer and Unusually Warm Year of 1995*. University of East Anglia, Norwich, 178pp.

The Scottish Office and EPSRC Global Environmental Change Programme (1998). *A Climate Mitigation Strategy for Scotland: Workshop Report*. Scottish Executive, Edinburgh, 19pp.

The Scottish Office and UKCIP (1998). *Climate Change Impacts in Scotland: Workshop Report*. Scottish Executive, Edinburgh, 21pp.

2.2 Wales scoping study¹

John F. Farrar²

2.2.1 Introduction

The Wales scoping study was commissioned by the Environment Division of the National Assembly for Wales. It produced summary (Anon., 2000) and technical (Farrar *et al.*, 2000) reports (both bilingual) and organised a one-day conference in Cardiff on 18 February 2000.

2.2.2 Main findings

The future climate of Wales based on current GCM simulations is presented in the UKCIP 1998 report (Hulme and Jenkins 1998). Preliminary downscaling suggests that there may be a small west-east gradient, with the greatest temperature increase in the east. Preliminary findings did not suggest any systematic effects of altitude.

Main impacts within Wales can be divided into: those on the natural environment; those on the environment in which industry and commerce operate; and those concerned with water management. Findings are derived from expert opinion and stakeholder interviews, and summarised by sector in Table 2.2a.

Stakeholders were generally well informed about issues (ecology, water and energy sectors were particularly well informed; business in general was less well informed together with, surprisingly, forestry). The ability of their institutions to adapt was often said to be limited because of some or all of: institutional inertia, conflicting institutional priorities, lack of certainty in the climate predictions, and the long timescale of climate change in relation to usual planning horizons. The stakeholders called for better predictions of climate, both with less uncertainty and with more detail of extreme events and local climate. Both stakeholders, and some members of the steering group, saw a clear Welsh dimension, wanting (for example) Welsh indicators of change, not just UK-based examples. This view was re-iterated at the 18 February conference.

Wales is sufficiently distinct from other regions of the UK for us to suggest that it should be proactive in adapting to climate change. Many decision-making bodies and utilities are Welsh or have semi-autonomous Welsh sections. Its ability to change is limited by the relatively low mean GDP and poorer skills base compared with other parts of the UK. There is a higher proportion of primary and manufacturing industry, and outdoor tourism is important to its economy. Rural issues are of great importance, and Wales has taken the UK lead in the

Table 2.2a Evaluation of the severity of climate change impacts in Wales by sector

| Sector | Severity of impact (1-5, where 5 is high) | Special issues |
|---------------------------|--|--|
| Flood defence | 5 | Coastal flood defence |
| Water supply | 5 | Possible summer water deficits |
| Biodiversity: terrestrial | 4 | Loss of raised bogs, arctic alpine species |
| Biodiversity: freshwater | 4 | Low summer stream flow |
| Agriculture and forestry | 4 | Land use changes |
| Tourism | 4 | Outdoor and beach tourism |
| Built heritage | 3 | Sensitivity to extreme weather |
| Business | 3 | Insurance sector |
| Transport | 2 | Susceptible to extreme weather |
| Energy | 2 | Mitigation policies will dominate |
| Human health | 1 | Reduced mortality overall |

¹ The Wales Scoping study was funded by the National Assembly for Wales. Study findings are presented in the report: Farrar, J., Vaze, P., Hulme, M. and Reynolds, B. (2000): *Changing Climate Challenging Choices: The impacts of climate change in Wales from now to 2080 – Technical Report*. Report prepared for the National Assembly of Wales. In press.

² Institute of Environmental Science, University of Wales, Bangor.

introduction of agri-environmental schemes, which has given it some experience of integrated planning. Wales has a very high proportion of land and coast with some degree of environmental protection, with three national parks and a higher density of Sites of Special Scientific Interest (SSSIs) than England, and its upland ecology is important and particularly sensitive. Its coastline is long relative to its area, and its population and tourism are concentrated on the coast. Wales exports water to England.

In the natural environment, it has been possible to identify species and communities whose range or frequency may increase (nightingale, kingfisher) or decrease (arctic-alpine plants, dipper). The design of Biodiversity Action Plans (BAPs), and the criteria for site designation of, for example, SSSIs and National Nature Reserves (NNRs) do not allow for climate change impacts. This is a serious problem as Wales has over 1,000 designated areas.

Human health will be affected, but impacts will be minor compared with other factors affecting future health, with reductions in winter mortality not being offset by a rise in summer mortality due to asthma, water- and insect-borne diseases, and skin cancer.

The energy and water supply industries are acutely aware of climate change and its long-term implications. Energy generation will be more affected by mitigation than by adaptation policies, although overhead lines will be subject to damage by severe weather. Water supply may be unable to meet summer demand over a significant proportion of Wales by 2025 due to the predicted changes in seasonality of precipitation. Much of the water abstracted in Wales is destined for England, adding a potential political dimension. The regulators of the water and power utilities set short-term, customer driven, goals for their sectors and these goals are notable in lacking any long-term environmentally based component.

Insurance is aware of and geared to the consequences of climate change. Since much tourism in Wales is outdoor, and 61% of it coastal, this sector will be significantly affected by climate change. The plans to extend tourism into the shoulder periods of autumn and summer may need to be revisited in the light of the

weather predicted for these periods of the year.

Other business sectors are less well informed or concerned, believing that they have the time and ability to make the necessary changes when climate necessitates it. We were not made aware of any businesses viewing climate change as offering opportunities for development and expansion.

Flood defence is set to become a major issue, and our conference took place just a week before the tenth anniversary of the Towyn floods, which caused considerable misery and economic damage.

The organisation of flood defence in Wales is complex, with the Environment Agency, the National Assembly, and local authorities, all having responsibilities (MAFF does not have a role in Wales, but its experiences in England will inevitably be relevant to Wales). Both coastal flooding (as a result of sea level rise, storm surges and wave heights in extreme weather) and inland flooding (as a result of rain concentrated in intense episodes exceeding the capacity of rivers and storm drains) are set to become significantly more frequent. A clearer and more transparent presentation of responsibilities and financial needs will greatly assist adaptation. There are clear implications for the planning of developments on floodplains and other areas which will be subject to flooding in the lifetime of the structures being planned. Revision of the appropriate planning guidance is consequently needed. Finding institutional solutions to the problems raised by these interactions represents a major challenge. Examples of interactions between sectors are outlined in Table 2.2b.

2.2.3 Key issues

Water emerged as the key issue. There may be difficulty providing adequate water supplies for Wales during dry summers by 2025. On top of this is the political dimension that nearly 60% of the water abstracted in Wales is destined for England. Flood control is the second key issue: much low-lying coastal land in Wales is critical for its importance economically, for habitation, for tourism, or for its natural habitats. Predictions of a ten-fold increase of frequency of conditions which now produce coastal or inland flooding need very serious consideration.

Table 2.2b Examples of interactions between sectors which will be driven by climate change

| Impacts on: | Related to: Terrestrial and freshwater habitats | Flood defence | Agriculture and forestry | Water resources |
|---|--|---|---|--|
| Agriculture and forestry | agri-environmental schemes; need for corridors between fragmented habitats | loss of agricultural land | - | low supply will restrict irrigation |
| Tourism | visual; potential for eco-tourism; fishing | visual | visual | visual |
| Water resources | need for water to maintain water-tables and river flows | need to ensure that inland flood defences allow water to be diverted to reservoirs and aquifers | need for irrigation; runoff and water quality | |
| Flood defence | | - | | need to divert inland waters to reservoirs and aquifers |
| Biodiversity and terrestrial and freshwater habitats | | loss of habitats; saline incursions may cause species loss | land use changes may cause loss of sites | low river flows and low water tables may cause species changes |
| Archaeology | | loss of sites from flood or construction of hard defences | loss of sites with land use changes | |
| Human health | insect vectors; water-borne pathogens | sewage in floodwater | water-borne pathogens; agrochemicals | water-borne pathogens |

The importance of rural issues in Wales, and their particular sensitivity to climate change, is notable; adaptation by change of land use in the managed environment will be the key.

A key issue for adaptation is the substantial degree of interactions between sectors and the need for more cross-consultation when planning, particularly for the long term. Wales has the potential advantages that: (1) it has experience from the agri-environmental schemes Tir Cymen and Tir Gofal of planning and decision-making across sectors; and (2) National Parks constitute a considerable percentage of its land area, and the Parks typically think and plan across sectors and on a long time scale.

2.2.4 Use of UKCIP framework including scenarios

UKCIP were involved at the tendering/interview

stage, and were on the Steering Committee. They were subsequently involved by: commenting on the draft questionnaire, checking the list of potential interviewees for overlap with other studies; discussing technical issues and available literature; and commenting on draft summary and technical reports. They provided invaluable advice on the reports and on the running of the final conference, at which they spoke. The UKCIP scenarios were the baseline from which the climate section of our study was conducted, and they provided the basic information used to inform the interviews with stakeholders.

2.2.5 Institutional structure for the study

The scoping study that has produced this report was initiated by the National Assembly for Wales. It was conducted by a team co-ordinated

by the Institute of Environmental Science, University of Wales Bangor, and including the Institute of Terrestrial Ecology, Bangor, ECOTEC Research and Consulting, and the Climatic Research Unit, the University of East Anglia, in collaboration with UKCIP. A steering group representing many institutions and interest groups within Wales advised the team.

The Environment Division of the National Assembly retained a lively and involved interest throughout, as did UKCIP. There was no involvement beyond the steering group of local government, agencies, or business. The summary and technical reports present: climatological modelling of Wales; expert review of 11 key sectors; and interviews of nearly 70 stakeholders drawn from a wide range of institutions and interest groups within Wales.

Successes: a large number of interviews (1/45,000 population) was conducted with a good contact rate and little or no record of interviewees having been contacted before. Transcripts will be archived with the National Assembly and UKCIP. Identifying Welsh uniqueness, prioritising likely impacts, and identifying research needs were all successful.

Weaknesses: The quality of expert/sectoral reporting was uneven. Due to the commissioning of the study by tender, it was less of a co-operative exercise than in other regions so there is still a need for a forum or group independent of the Assembly to take issues forward. Background literature could not be fully covered with the time and finance available. Neither was there any study of the knowledge and attitudes of the Welsh public, or of socio-economic scenarios tailored to the unique features of Wales.

Both summary and technical reports are web-mounted at www.bangor.ac.uk/ies/ies.html and there is provision for sending in comments electronically. These comments will be mounted after editing.

2.2.6 Main recommendations

We were asked to make recommendations to the National Assembly. Detailed recommendations appear in the technical report; here is a summary:

- The Assembly needs to ensure that climate

change is considered as a component of sustainability – a key cross-cutting theme of the Assembly – in determining policies.

- The Assembly needs to develop economically viable strategies which recognise the interactions between climate change, agriculture, conservation and water resources.
- The Assembly needs to take account of the potential impacts of climate change in revising planning guidance (Technical Advice Notes) particularly in areas susceptible to flooding.
- The Assembly also needs to influence Building Regulations to ensure that they address climate change impacts during the lifetime of the structures being planned.
- Regulators need to ensure that the water and power utilities place sufficient emphasis on measures to assist adaptation to climate change. In the longer term, there may be pressure to build reservoirs in Wales to supply consumers in England. This will raise significant political issues.
- Government needs to clarify the responsibilities for flood defence which are distributed between a range of bodies.
- The Assembly and Welsh organisations need to ensure that Welsh issues are fully incorporated into UK-wide research on climate change impacts.
- Organisations need to consider how corporate strategic plans should be informed by a wider range of issues than currently, due to the high degree of interaction between sectors which climate change will highlight.
- Business needs to consider the opportunities as well as the threats offered by climate change.
- The Assembly needs to consider setting up a forum of local stakeholders and experts: to exchange information, concerns and ideas; to act as a focus and facilitator for the climate change debate; and to start building the networks which are needed to underpin integrated planning.
- The Assembly and other organisations need to consider how to increase public awareness of climate change issues.
- Research is needed as recommended in the next section.

2.2.7 Research priorities

Research needed for decision-making within Wales should be planned and conducted in the context of what is occurring in the rest of the UK. The following priorities were identified:

- Socio-economic scenarios need to be developed for Wales, taking account of the regional economic statistics to provide a more detailed picture of how the interaction of climate change and socio-economic scenarios might impact on Wales.
- There is a need to advocate and support research on the impacts in sectors such as freshwaters, upland habitats, agriculture and forestry. In particular, the interactions between climate variables and nitrogen deposition, acid rain, ozone and overgrazing, and the impact on agricultural pests, need more study.
- There is a need to advocate and support research to determine how local climates in Wales will be affected, particularly the nature and frequency of extreme climatic events.
- There is a need to select indicators of climate change within Wales, consistent with the UK indicators, and make arrangements for collecting data.

2.2.8 References

Anon. (2000) *Wales – changing climate, challenging choices*. Summary report. National Assembly for Wales.

Farrar, J., Vaze, P., Hulme, M. and Reynolds, B. (2000) *Changing Climate Challenging Choices: The impacts of climate change in Wales from now to 2080 – Technical Report*. Report prepared for the National Assembly of Wales. In press.

Hulme, M. and Jenkins, G. (1998). *Climate Change Scenarios for the United Kingdom*. UKCIP Technical Report No. 1, Climatic Research Unit, Norwich, 80pp.

2.3 Climate change impacts in North West England¹

Simon J. Shackley²

2.3.1 Main findings on vulnerability

Of the large number of potential impacts identified in the North West England study only the most vulnerable impact domains are described here, these being: the coastal zone, the rural uplands, water resources, insurance and manufacturing industry (SNW 1998, Shackley *et al.*, 1998).

The coastal zone

The 430km coastline of North West England is generally low-lying and much of its southern length is urbanised. A number of rivers empty into large tidal estuaries, including the Mersey, Ribble, Wyre and Kent. Some 95,000 people in 38,000 houses are located in the coastal flood plain, which constitutes 2.7% of the land area of the North West. The coastline and adjacent estuaries are home to major sites of manufacturing with installations operated by large companies including ICI, BNFL, Shell, BAe Systems, British Energy, GlaxoWellcome, Albright & Wilson and Unilever. The coastal zone is also home to tourist destinations such as Blackpool, Southport, Lytham St Anne's, Morecambe, Grange-over-Sands and Arnside. Much of this development occurred in the 19th century as a result of industrialisation: from today's perspective, some of that development would not be regarded as desirable, due to the low-lying topography.

Major floods have been experienced in the region over the last century, most recently in 1983, 1987 and 1990. Between a half and a third of the coastline is protected by 'hard' defensive structures and a further 280km of defences protect land adjacent to estuaries. Most of the large area of land below the 7m AOD (above ordnance datum) contour is protected, though the present high tide levels often exceed 6m (Crellin & Diamond, 1993). Coastal defences provide protection to inland urban areas, including towns such as Preston and Warrington located many miles from the sea on the upper tidal reaches of rivers, but 40km² of valuable peat soil horticultural land in south west Lancashire is well below the mean high spring tide level and is only prevented from flooding by an extensive network of drainage ditches, coastal defences and pumping stations. Several hundred years ago this area was a component of the lowland mosses and wetlands which stretched across North West England. Further back in time a large shallow lake – the largest in England in terms of surface area – stretched from what is now the RSPB reserve at Martin Mere to the sand-dunes along the Sefton coastline.

Sea-level rise has already been observed at Liverpool (12cm over the last century); however marine engineers consider that the coastline is most susceptible to a combination of increased tidal ranges, tidal surges and increased wave heights. Methodologies for estimation of how climate change will influence extreme events are undeveloped. Theoretical considerations led Rossiter to suggest that: "a rise in sea level of 15cm ... would treble the probability of storm surges exceeding danger level in the Irish Sea"

¹ The North West England scoping study was commissioned by: the North West Regional Chamber, the North West Regional Association, Sustainability North West, North West Water, the Environment Agency, The National Trust, the Government Office for the North West and AXA Insurance. Study findings are presented in the report: Shackley, S., Wood, R., Hornung, M., Hulme, M., Handley, J., Darier, E. & Walsh, M. (1998). *Changing by Degrees – The Impacts of Climate Change in the North West of England: Technical Overview*, University of Manchester, Manchester, 63pp.

² Manchester School of Management, UMIST

(quoted in Tooley, 1995). The Irish Sea Forum suggested that: "Floods which are now expected to occur once in 200 years could occur once in 20 years if the average sea-level rises by 40cm".

A key question for coastal defence is what standard of protection is provided to those areas which need upgrading in the next few decades. Where large resources have been devoted to recent major improvements (e.g. Blackpool's £50 million and Morecambe's £20 million defences), sufficient 'climate change headroom' is likely to have been incorporated within their design life of 50 years or so. Other urban areas will in all likelihood continue to be protected to today's high standard. The real issue will focus upon what happens in rural areas important for agriculture and biodiversity. The mudflats and salt marshes which occur between the Solway Firth and the Dee Estuary, and include large stretches around Morecambe Bay, and along the Ribble, Wyre, Lune and Mersey Estuaries, are a focal point on the Eastern Atlantic Migratory Flyway. Between 10% and 30% of the UK's population of birds such as knot, curlew, oystercatchers, pink-footed geese, bar-tailed and black-tailed godwit and sanderling take advantage of these mudflats. Some 20,000 hectares of the Lancashire coastline are therefore designated as a Ramsar site, Morecambe Bay and the estuaries of the Ribble, Mersey, Dee and Solway are all Special Protection Areas (SPAs) and Morecambe Bay is a candidate Special Area for Conservation (SAC). Coastal squeeze due to climate change will reduce the area of mudflats and salt marsh available unless managed realignment is feasible. Agricultural land will be vulnerable, especially where that land has been reclaimed from the natural area of coastal inundation (e.g. around Pilling on the Fylde Plain) or where it is only sustained through pumping (e.g. Crossens near Southport).

Some ports and harbours are vulnerable to rising sea-levels, high tides and surges. Those with lock gates can exclude the sea, though overtopping is still a risk, causing damage to vessels, property and land. Twenty-four hour ports such as Heysham Harbour are most at risk and flooding and strong south westerly winds are already regarded as a risk at

Heysham, where they can cause damage and delays. Adaptation of existing infrastructure (dock heights, storage facilities, loading equipment and ships themselves) will be necessary, though perhaps within the natural replacement timescale for equipment of the next few decades. The change in siltation patterns of rivers associated with changing rainfall patterns may also be important to some harbours. In Heysham, for instance, the low flow of the River Lune due to the drought of 1995, may have altered sedimentation and the river's position, subsequently bringing more sediment into the shipping channel and costing £125K in extra dredging costs in one year.

Rural uplands

The North West of England contains a wealth of upland land, from the Cumbrian mountains to the Forest of Bowland, the Western and Southern Pennines, and Peak District fringes. There is a high degree of specialisation amongst plants and animals to a relatively cold, maritime climate. There are also species at the southern edge of their distribution, such as the three remnant Arctic fish populations in the lakes of Cumbria (the Vendace, Shelley and Arctic Charr) and Arctic-Alpine plants including Mountain Avens, Alpine Lady's Mantle and various saxifrages and sedges. Even a modest warming has the potential to produce far-reaching changes in the distribution of such specialised species, though there is evidence that these populations are genetically distinct and hence may have already adapted to the relatively more clement climate of the region. In addition, much upland land permits migration upwards and northwards (*contra* the developed lowlands around the conurbations of Merseyside and Greater Manchester), though the extent of this would be limited for species in the isolated Cumbrian massif.

Unfortunately, current climate models are too coarse to represent upland areas, though application of statistical downscaling techniques in the Pennines suggest potentially dramatic changes could occur. Pepin (1995 & 1997) for instance, found that a 2°C warming would reduce sub-marginal land from 25% (current) to 2% of land cover and reduce the number of frosts by 50%. A 50 year temperature record at two Pennine stations

does not show warming compared to the region as a whole; some have proposed that the lapse rate may change as the climate changes.

Much of the uplands consist of heather moorland and this may see more blanket peats and bog mosses develop as rainfall increases, and an increase in currently marginal species such as crowberry. Bell heather, currently temperature limited, may move upwards whilst purple moor grass might also expand onto higher land. Temperature increases could also favour the return of scrub oak, birch and willow (grazing dependent). Other plants which reach the limits of their northerly distribution in the low carboniferous hills of southern Cumbria might extend northwards, including Old Man's Beard, Black Bryony, and Horseshoe Vetch. Species such as beech and small-leaved lime are also likely to extend their northerly range, whilst species such as cherry, alder and willow could suffer from higher soil moisture deficits in the growing season. Overall, as in the lowlands, the existing semi-natural vegetation is likely to be subject to stronger competition with negative impacts upon 'stress-tolerator' species, including most of those with high conservation value. Recent outbreaks of upland pests such as the heather beetle highlight the potential adverse impact of climate-induced changes in pests and diseases.

Extreme events, in particular droughts, will change the balance of upland species, e.g. between heather and bracken, and between tap rooted forbs and the shallow-rooted plants invading from the valley bottoms. The number of grassland and heathland fires in North West England is closely correlated with dry hot seasons (low rainfall rather than high temperature being the key variable). Upland fires can require expensive actions to put them out (£70K in one recent case) and subsequent land restoration and water treatment can be costly if part of a reservoir catchment. The altitudinal limit to production forestry could increase but exposure and the effects of strong winds in dislodging trees (windthrow) are likely to remain the limiting factors here.

Upland rivers, streams and lakes are sensitive to weather variability, as illustrated by the remarkable correlation between the position of the Gulf Stream and the physics and biology of

Lake Windermere. Coarse fish will begin to do better than trout and salmon, though not until water temperatures are significantly higher (some 4°C warmer than at present). Extreme events such as high flows destroy habitats and increase erosion, whilst low flows limit the availability of fish spawning sites.

Research has now shown a strong relationship between intensive sheep-grazing in the uplands and erosion, sediment transfer, high stream and river flows and vegetation characteristics. Winter flow in the River Lune has increased by a fifth in the last 80 years, and down-stream floods are 3 to 4 times more frequent. A move towards more winter rainfall combined with upland erosion accounts for such changes. Any impacts of climate change are likely to depend to an important extent upon change in the intensity of sheep grazing and other land management decisions such as drainage, bracken spraying and encouragement of woodland. Lastly, climate change is likely to change the appearance and perception of the upland landscape. Less snow and frosts, and hotter, possibly drier summers, will, over time, change the cultural characterisation of the 'uplands' by its inhabitants and visitors.

Water resources

The North West of England is infamous for the amount of rain it receives and yet because most of the water supply is surface water, prolonged drought can have a profound impact on supplies. The 1995/6 drought was one of the worst on record.

Reservoir stocks declined to record low levels – less than 10% at Thirlmere and Haweswater in Cumbria (which supply the urban conurbation to the south), whilst many Pennine reservoirs were effectively empty (even though they had been full in early Spring 1995). Consumer demand reached record levels in the summer of 1995 (more than 10% above normal), though voluntary requests and a hosepipe ban did bring demand levels nearer to normal. The situation faced in neighbouring Yorkshire (where water was tanked in) was avoided in North West England by the integrated water system which allowed water supplies to be provided from the River Dee, albeit at an additional cost to North West Water of several million pounds. If hotter,

drier summers and wetter winters were to become more frequent, it will be necessary to collect more water during winter, by e.g. pumping river water into reservoirs and/or additional reservoir capacity.

Unfortunately for long-range water planning, the UKCIP climate scenarios are of low confidence vis-à-vis precipitation change and only provide monthly average changes. When applied to the water resource models of North West Water, the different climate scenarios provide conflicting answers regarding their impact upon the water supply-demand balance.

Discolouration of water is likely to become more acute as temperatures (and hence decomposition rates) increase, and periods of drought followed by intense rainfall events become more common. The requirement for removal of colour from water will incur higher treatment costs. Climate change is also likely to impact on waste water management. There are a large number of Combined Sewer Overflows (CSOs) in North West England, dating back to Victorian times. These are already prone to flood during intensive rainfall, resulting in 'foul flooding' of properties, infrastructure and waterways. Modern waste water treatment facilities are designed to cope with three times the projected load, but climate change may increase the frequency of more extreme rainfall events, exceeding excess capacity and causing flooding. Drought can also cause water-based pollutants to become concentrated, and be flushed out during subsequent intensive rainfall, with negative impacts upon ecology (as observed in the aftermath of the 1995/6 drought).

Insurance

The risk to insurers is principally related to increased flood risk and storm damage from climate change at the coast, along estuaries and river floodplains. One company estimated that its exposure to flooding along the coastline of North West England was in the region of £190 million, and the value for all companies might well be an order of magnitude larger. The insurance sector is able to respond rapidly to climate change by changing its yearly premiums and/or by greater differentiation, i.e. higher premiums for higher flood-risk properties and/or requirements that

precautionary actions be taken. Room for manoeuvre in the sector is limited, however, by fierce competition, incomplete and uncertain information, the move towards larger companies with less local and regional knowledge, the relatively cheap availability of re-insurance and the commitment to equity rather than differentiation. Nevertheless, we are likely to see at least some insurance companies being more pro-active vis-à-vis the risks they underwrite and requesting further information from the Environment Agency and local authorities. One insurance company has, for example, refused to provide cover for the ground floor of river-side properties which are at high risk of flooding, yet where residents have resisted the construction of a new flood wall defence for aesthetic reasons.

Manufacturing industry

A distinctive feature of the North West England study was the canvassing of the viewpoints of approximately 30 environmental managers in the manufacturing sector. Some 25% of the UK's chemical industry is located in North West England, whilst it is home to 20% (400) of the UK's sites registered under Integrated Pollution Control legislation. There is £35 billion of plant investment in the Mersey Estuary region alone. More extreme air temperatures (above 25°C or 30°C) would limit the effectiveness of some currently installed cooling systems in the chemicals industry, increasing running costs or requiring installation of new equipment (at additional costs of £100s to £100,000s). Many firms abstract water from rivers and lakes: the availability and quality of abstracted water can be adversely affected by intensive rainfall (through increased turbulence) and low flows, perhaps requiring installation of new water treatment or closed water systems. Discharges of wastes into water ways might also be limited in periods of drought, whilst the capacity of on-site waste water treatment systems designed to cope with a 1:3 or 1:5 year intensive rainfall event could be exceeded more frequently, resulting in ecological impacts and a need for greater waste water capacity. Rising sea levels and tidal surges are also of concern for the large number of coastal-based sites, with flooding during high tides already a problem for some firms, e.g. those along the Wirral and in Lancaster.

High summer temperatures can also affect working conditions. Several firms reported adverse impacts upon the workforce during the hot summer of 1995 including more delays, breaks and lowered productivity. The problem was especially acute where protective clothing is worn, driving up ambient temperatures to above 30°C. At least one firm has installed air conditioning in response, at considerable expense.

2.3.2 Key issues emerging

The role of extreme events

The history of weather-related incidents in North West England suggests strongly that it is extreme events with negatively perceived impacts which drive policy focus and actions in response. Coastal flooding in the 1970s and 1980s, with economic and social costs, led to investment of significant resources in coastal defence, whilst the drought of 1995/6 led to a significant shift in attitudes towards water resources in the region. The hot summers of the 1990s, and inland flooding in the last few years, have led to many companies viewing the climate change issue as a subject worthy of further investigation. Climate change provided stakeholders with a framework in which to interpret the lived experience of weather-related impacts. The impacts of climate change were not simply accepted as ‘fact’, however, and many environmental managers suggested that they would for the moment adopt a ‘wait and see’ policy. If extreme events consistent with climate change became more frequent (e.g. four ‘1995-type’ summers in a row, or 12 weeks of temperatures over 25°C) then firms would probably invest resources in responding. In other words, the companies contacted needed fairly strong ‘on the ground’ evidence that weather-related extreme events at their specific plants were changing before taking action which incurred a financial outlay. Nevertheless, extreme events act as a ‘hook’ by which stakeholders become aware of, and think through the impacts of climate change (even though a scientifically rigorous relationship between individual extreme events and long-term climate change is not currently possible).

Climate and other socio-economic changes

A general scheme for classifying the stakeholder responses to climate and other changes is illustrated in Figure 2.3a, using two axes: sensitivity (vulnerability) and uncertainty. Climate change is more frequently perceived as being located towards the bottom right hand corner of the figure, whereas most stakeholder attention will be directed toward the top left hand corner (including issues in the environmental domain such as packaging, the climate change levy and waste regulations). The salience of climate change also depends upon other, frequently short-term, changes in markets and policies. For example, the environmental manager at a chemical firm considered that reduction of throughput of one process due to increased extreme air temperatures would not matter at the present time due to suppressed demand for the end product. The evaluation of vulnerability and readiness to adapt would have been quite different 10 years ago, when global demand was much higher. More generally, market conditions will have a major influence upon vulnerability to climate change: e.g. if markets are buoyant extra investment to adapt plants to climate change can be afforded.

Other environmental policies may also influence the vulnerability of processes to climate change. At one textiles firm, for instance, the company replaced solvent-based inks with water-based inks to reduce rogue emissions of Volatile Organic Compounds (VOCs). As a higher temperature is required to use water-based inks, there could potentially be an increase the demand for cooling of the factory to improve working conditions.

Even though climate change is rarely identified as a key driver – and even though vulnerability to climate change cannot frequently be known without considering what will occur in other key drivers –there may be an informal trade-off between uncertainty and vulnerability. Since climate change is relatively more certain than most other long-term issues it could provide an ‘island of certainty’ into the future, which may then help the organisation to plan into the future on other issues. This may elevate assessment of climate change impacts beyond the evaluation of vulnerability alone.

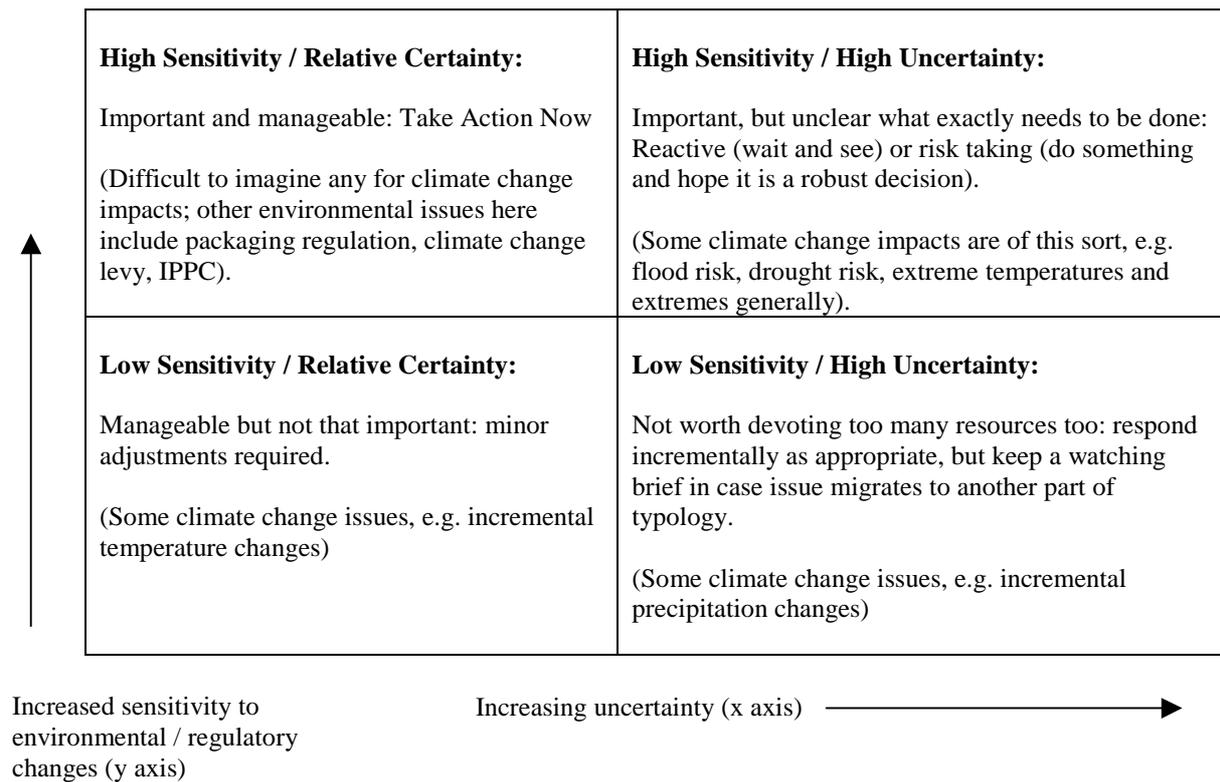


Figure 2.3a: Classification of stakeholder responses to climate and other changes

2.3.3 Institutional structure

The following factors were critical to the establishment and reception of the study:

- Early sponsorship by an influential County Council planning officer (Mr Graeme Bell);
- Subsequent sponsorship and endorsement by a partnership between local and regional government and industry, providing stakeholders with a clear sense of ‘ownership’;
- National-level encouragement and support from UKCIP;
- Management of the work by Sustainability Northwest (SNW), an NGO set up and supported by the North West Business Leadership Team and governmental bodies;
- A professional communications and outreach effort conducted by Mr Steve Connor at SNW;
- Involvement of a senior and well-known academic in the region (Professor John Handley) and the prestigious Climatic Research Unit (CRU);
- Presentation of the possible benefits of climate change to the region (e.g. tourism, recreation, health, lifestyles and agriculture) as well as the possible threats, giving the media a new way to present climate change issues;
- The wide range and number of stakeholders contacted (160 interviews carried out);
- The use of climate analogues, in particular the hot summer of 1995 to illustrate an average summer in terms of temperature in the 2050s;
- The strong evidence of climate change over the last 50 years from regional temperature and rainfall records;
- Availability of government-endorsed climate change scenarios for the UK;
- The occurrence of extreme events within the several years preceding the study: river flooding, droughts, hot summers, intense rainfall events, etc., which could be interpreted within a climate change framework.

The North West England study entwined different knowledge sources to form a resilient

network (see Figure 2.3b). This included authoritative academic knowledge of climate changes past, present and future; bureaucratic knowledge of policy processes; local, site-specific knowledge of industrial facilities, rivers, biodiversity, water resources, etc.; and political knowledge of how to communicate to the media and influential stakeholders.

2.3.4 Main recommendations

- Organisations should adopt an incremental experience-based approach to climate change, that is they should monitor the effects of climate change upon operations, systems and markets in a sequential fashion. They should also be prepared to reassess decisions and institutional arrangements in response to new knowledge of climate change.
- Public and private decision-making should incorporate an assessment of whether climate change could influence the outcome or selection of a decision and, if so, adapting the decision so that it would be robust to a range of possible climate changes.
- One approach is identification of ‘climate change headroom’. The water industry already use a headroom concept in planning to take account of uncertainty in future demand/ supply, and coastal engineers typically incorporate a ‘freeboard’ in the design of flood defences. The application of the climate change headroom concept could be extended to issues such as waste water management, working conditions, insurance, cooling requirements and process design. In sectors where an exceedance of a quantitative standard cannot be measured, the headroom concept would perhaps be less useful, e.g. in biodiversity.
- Policies which can influence the vulnerability of systems to climate change should be used in addition to direct adaptation measures. For example, upland land management can limit erosion and stress upon vegetation, hence reducing its vulnerability to future climate change.

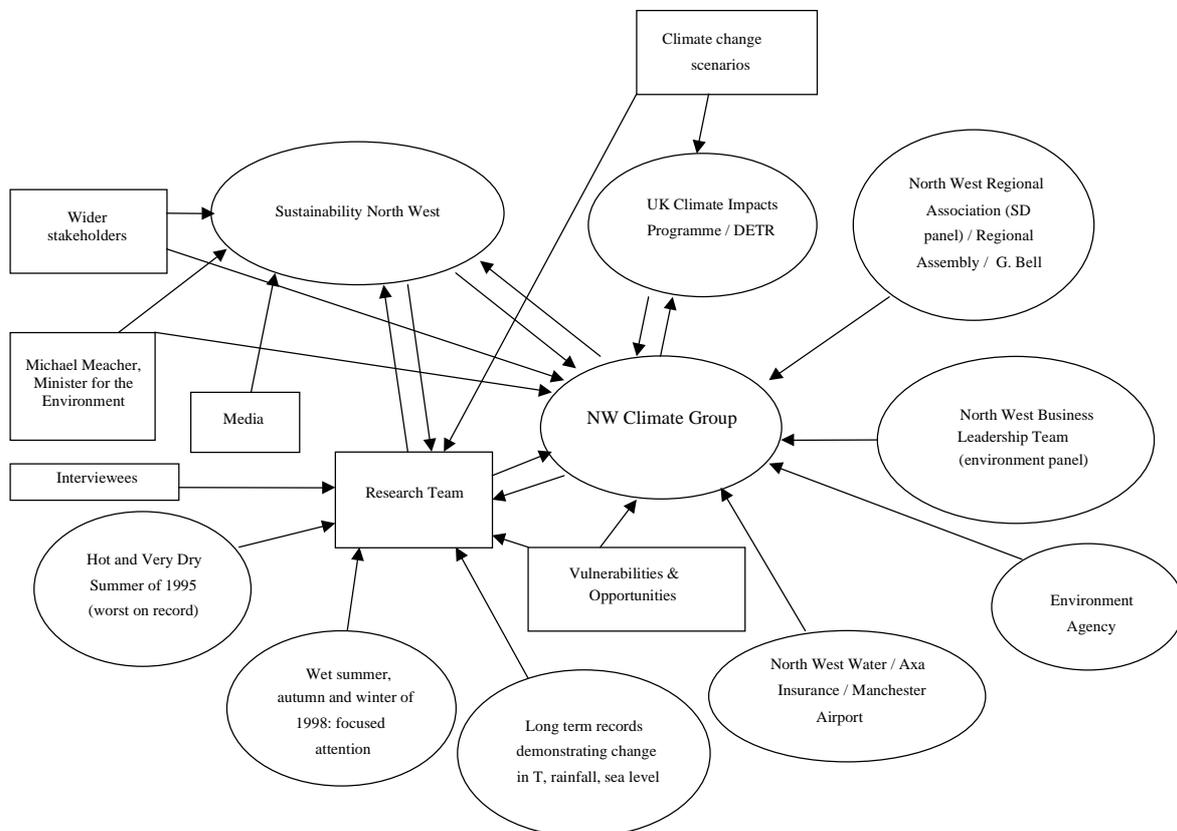


Figure 2.3b: Actor-network (arrows indicate active involvement)

2.3.5 Future research priorities

The following areas of knowledge required for future policy development, together with potential partners, were identified in the Technical Report on the North West England scoping study:

- Development of regional climate change scenarios;
- Localised studies of coastal zone management;
- Upland management;
- Impacts of climate change upon peat soils;
- Impacts on agriculture and forestry;
- Lakes, water quality and climate change;
- Impacts upon regional manufacturing industry;
- COMAH (control of major accidents and hazards) regulations on accidents and hazards;
- Leisure, tourism and the weather;
- Regional macro-economic impacts;
- Climate change indicators and reporting.

2.3.6 References

Crellin, J. and Diamond, M. (1993) Managed Retreat: The National Rivers Authority Perspective. In: *Rising Sea Level and Coastal Protection*, Seminar Report, Ulster Museum,

Belfast 22nd April 1993, Oceanography Laboratories, University of Liverpool, pp. 41-48.

Pepin, N.C. (1995). The use of GCM scenario output to model effects of future climatic change on the thermal climate of marine maritime uplands. *Geografiska Annaler* **77**(A): 167-185.

Pepin, N.C. (1997) Scenarios of future climate change: effects on frost occurrence and severity in the maritime uplands of northern England. *Geografiska Annaler* **79**(A): 121-137

Shackley, S., Wood, R., Hornung, M., Hulme, M., Handley, J., Darier, E. & Walsh, M. (1998). *Changing by Degrees – The Impacts of Climate Change in the North West of England: Technical Overview*, University of Manchester, Manchester, 63pp.

Sustainability North West (1998) *Everybody has an Impact – Climate Change Impacts in the North West of England: Summary Report*.

Tooley, M.J. (1995). Sea-level changes in *Irish Sea Forum, Coastal Zone Planning County Hall*, Preston, 19th January 1995:pp.3-14

2.4 The South East England scoping study¹

S. D. Wade², J. Hossell and M. Hough

2.4.1 Introduction

The Impacts of Climate Change in the South East England Scoping Study started in February 1999 and its findings were presented at a conference on 25th November 1999 at the Royal Geographical Society, London. It was the second integrated scoping study in the UK following the North West England study that was published in December 1998 (Section 2.3).

The study was based on a review of the climate change impacts literature and consultation with over 100 stakeholders, mostly from regional government agencies, NGOs and private industry. The impacts assessment focused upon 10 broad sectors: water supply; coastal issues; river flooding; agriculture; forestry;

ecology; cultural heritage; leisure and tourism; economic sectors; and insurance. Telephone or face-to-face interviews within these sectoral groups were conducted by experienced experts in each area.

The study findings were presented in detail in a Technical Report (Wade *et al.*, 1999) and widely distributed in a short Summary Report (circulation of 6,000 copies). This paper aims to provide an overview of the main findings of the study and take the work forward by:

- Identifying key features of South East England that make it particularly vulnerable to climate impacts;
- Describing some of the key issues that emerged from the study;
- Reviewing current progress in the

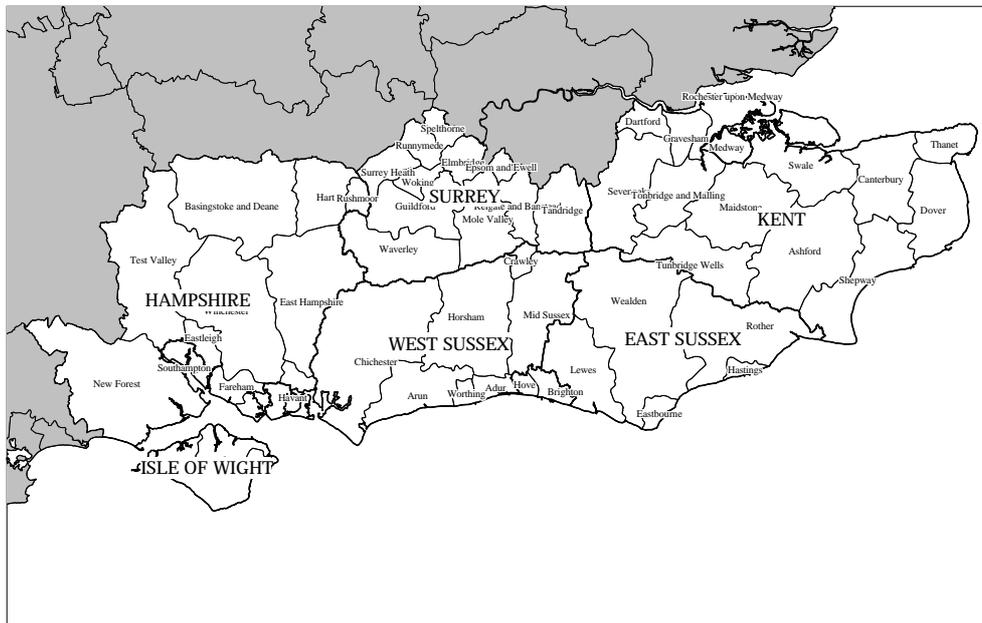


Figure 2.4a: The South East study area

¹ The South East England scoping study was commissioned by: Surrey County Council, Kent County Council, West Sussex County Council, Hampshire County Council, the Wildlife Trusts, The National Trust, the World Wildlife Fund, Country Life magazine, the Government Office of the South East, the Environment Agency and Thames Water. Study findings are presented in the report: Wade, S.D., Hossell, J. and Hough, M. (eds.) (1999). *The Impacts of Climate Change in the South East Technical Report*, WS Atkins, Epsom, 100pp.

² WS Atkins Water, Epsom, Surrey

development of adaptation strategies and outlining future needs; and

- Prioritising future regional research requirements.

The South East of England

The study area included the counties of Hampshire, West Sussex, Kent and Surrey and the Isle of Wight (Figure 2.4a). With a population of over 4.2 million, South East England is one of the fastest growing regions of the UK. The economy is critical to the UK as a whole and in 1995, the value of output from the regional economy amounted to £83,194 million, 16% of the English total. Individual economic sectors are growing fast in parts of the region, for example, Business Services (Surrey), Information Technology (North Hampshire) and Biotechnology (Surrey). There is pressure to build commercial and domestic property on green-field sites, and, by 2016, up to 1 million new households may be built in the region.

The region's environment is consequently at risk from over development and planning restrictions are required to protect distinct landscapes, such as the South Downs and precious ecological habitats such as ancient woodlands, heathlands and chalk streams. Outside urban areas over 50% of all land is covered by national or international designations. This year the South Downs and New Forest will become National Parks and much of the regions' 1200km coastline is protected by Special Protection Area (SPA) and Ramsar status.

A stakeholder approach

The South East England scoping study was led by key regional stakeholders with an interest in how climate change might affect the region. Surrey County Council initiated the study and with the help of UKCIP brought together a group of 12 funding partners. Six representatives formed a Project Steering Group (PSG). The project research team was drawn from WS Atkins, The Met. Office and ADAS. Each member of the team had specialist technical expertise and working relationships with many key regional businesses and government agencies. There were monthly meetings including an interim presentation to the Project Funding Group. There was also weekly contact between the PSG chair and the project

team manager. These arrangements created a collaborative research process that enabled (a) effective networking for arranging interviews and locating key data sources; (b) timely constructive criticism (if and when needed) and (c) the incorporation of expert opinion and ideas from all the study partners as well as the study team.

Through this process of collaboration 170 stakeholders were identified and sent a project summary sheet describing the main climate impacts in the region and a request for information. Follow up interviews or further correspondence with over 100 individuals from 80 stakeholder institutions provided the basis for many of the key findings of the study.

2.4.2 Climate change in the South East of England

Historic climate

Changes in temperature in South East England over the past 100 years broadly follow those in England as a whole over the same time period, with a rise in mean annual temperature of about 0.5°C. Summer rainfall at two sites analysed show a slight decrease in summer rainfall but no change in winter rainfall. Other indicators, such as the flow regime of the regions largest river, the Medway, suggest an increase in variability in the 1990s but no significant trend in average annual or seasonal runoff. Tide gauges around the coastline of South East England consistently show rates of sea level rise between 1mm per year on the Kent coast to up to 10mm per year in the Solent. Selected indicators of the region's past climate are shown in Figures 2.4 b-e.

Future climate

The main climate change predictions for the 2080s, in comparison to the climate for the 1961 to 1990 period, and under the full range of UKCIP scenarios, are as follows:

- | | |
|--|------------------------------------|
| ▪ Mean annual temperature | + 1.2 to + 3.4 °C |
| ▪ Mean annual rainfall | + 1 to + 4 % |
| ▪ Winter rainfall | + 6 to + 22 % |
| ▪ Summer rainfall | - 8 to - 23 % |
| ▪ Summer cloud cover | -3 to - 4 % |
| ▪ Mean annual wind speed | 0 to + 0.09 m s ⁻¹ |
| ▪ Summer evaporation | + 0.45 to + 0.91mm d ⁻¹ |
| ▪ Relative humidity | remains fairly constant |
| ▪ Increase in temperature and rainfall | variability |

For the medium high scenario:

- Mean sea level in the English Channel + 54 cm
- A “1995” summer – almost every year.
- A wet winter (160% of normal rainfall) – probability of 33% as compared to 6 % with present climate.
- A dry summer (50% of normal rainfall) – probability of 10% compared to 1% with present climate.

These results show there will be a small change in average annual conditions and a significant change in the seasonal variation of rainfall. The most noticeable impacts may be seen in any change in the frequency of extreme events such as droughts, intense storms and high windspeeds (Table 2.4a).

2.4.3 Impacts of climate change: regional vulnerability

The South East England study identified the main threats and opportunities presented by climate change. There were many examples of positive changes, for example: the benefits to plant and animal species that are currently at the northern edge of their range; longer growing seasons; opportunities to grow novel crops; and increased potential for the region’s leisure and tourist industries.

The three major impacts themes that developed during the study were coastal management, the changing countryside and water supply. The vulnerability of South East England for these themes, in terms of negative climate impacts and possible adaptation pathways, is summarised in Table 2.4b.

The coastline of South East England is highly developed with almost continuous sea defences around 1200 km of the coast. The predicted rates of sea level rise combined with the possibility of increased storm activity and wave energy was a major concern for stakeholders in some industries, the Environment Agency (responsible for flood protection) and MAFF (responsible for coastal defences). There are a range of possible adaptation responses to sea level rise. The design of new sea defences, such as the recent scheme at Bournemouth, typically assume a rate of sea level rise of 6mm per year,

which will be sufficient in most areas to protect the coast against climate impacts. However in other areas, older defences do not have climate change “built-in” and the costs may out-weigh the benefits when it comes to maintaining or extending these flood defence schemes in future. In the short term new development along the coast and within the tidal floodplain may be restricted and in the long term coastal industries may need to relocate. The risks to the coastline are high and adaptation strategies will involve making many difficult choices.

The South East of England is characterised by higher than average household demands for water ranging from 153 to 167 l h⁻¹ d⁻¹ (litres per head per day for individual company areas) compared to a national average of 146.5 l h⁻¹ d⁻¹ (WS Atkins, 1999). Meeting the demand for water is an important challenge for water companies in the region and during the summer of 1995 three companies imposed restrictions on water use, including hose-pipe bans. There were also problems on a smaller scale in 1990, 1991 and the summer of 1999 making the 1990s the worst decade on record for supply problems in South East England. The change in seasonal rainfall patterns may benefit groundwater recharge but research suggests that rivers are likely to suffer lower flows in the summer, impacting on river ecology and restricting the amount that can be taken for agricultural and domestic supply (Arnell *et al.*, 1997). Adaptation pathways for the water industry are well defined but some will be difficult and very expensive to implement, making this sector vulnerable to climate change.

While the adaptation choices for coastal flood defence are quite clear, the management of countryside change is less certain. Coastal “squeeze” will result in the loss of salt marshes and mudflats and there are few places on the South Coast where there are opportunities for habitats to migrate in land. Distinct landscapes in the South East of England such as the Hampshire Downs, South Downs and New Forest will change as temperatures rise and the soil water balance changes. Some species will flourish while others less suited to the new conditions will suffer. On lowland grasslands, valued species like Adonis Blue butterflies and some orchid species may become more widely distributed. Similarly, change on heathlands may benefit rare reptiles such as the sand lizard.

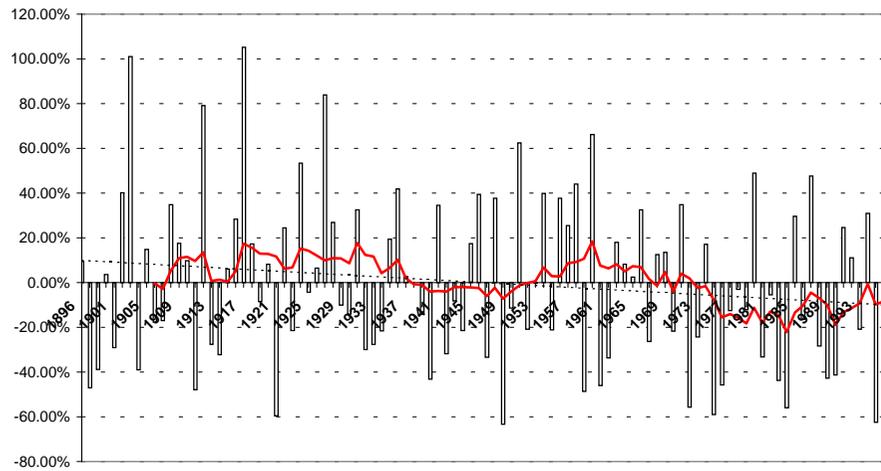


Figure 2.4b: Percentage change in summer rainfall, Falconhurst, Kent

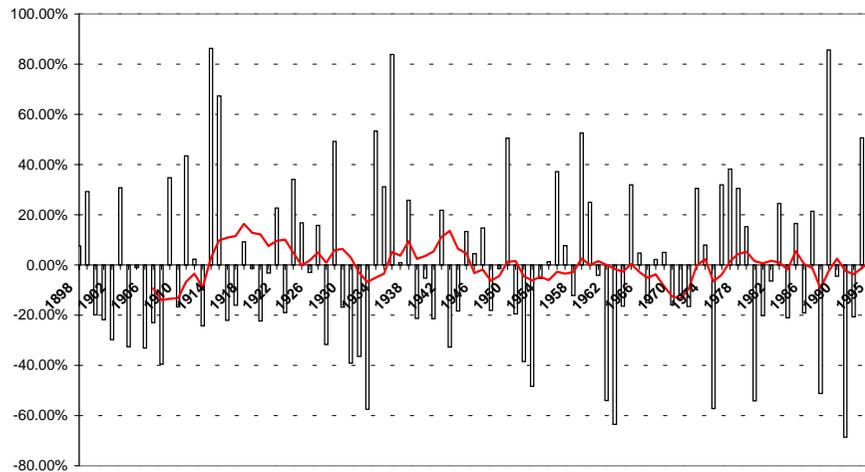


Figure 2.4c: Percentage change in winter rainfall, Falconhurst, Kent

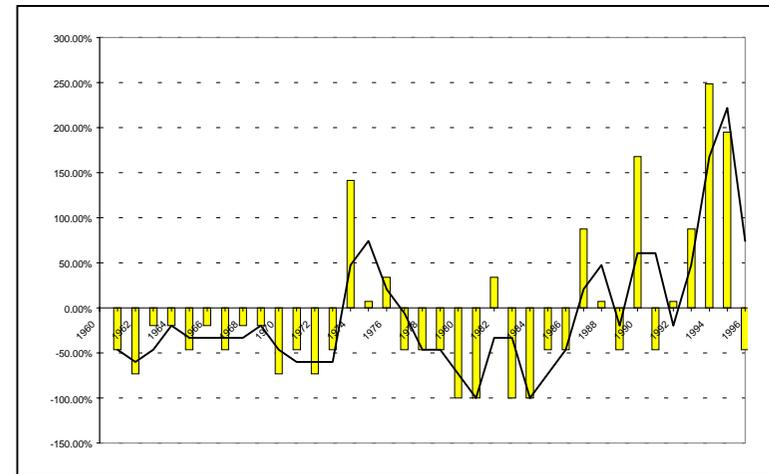


Figure 2.4d: Historical flows on the River Medway at Teston – change in the number of days above or below average number of days with Q1 flows

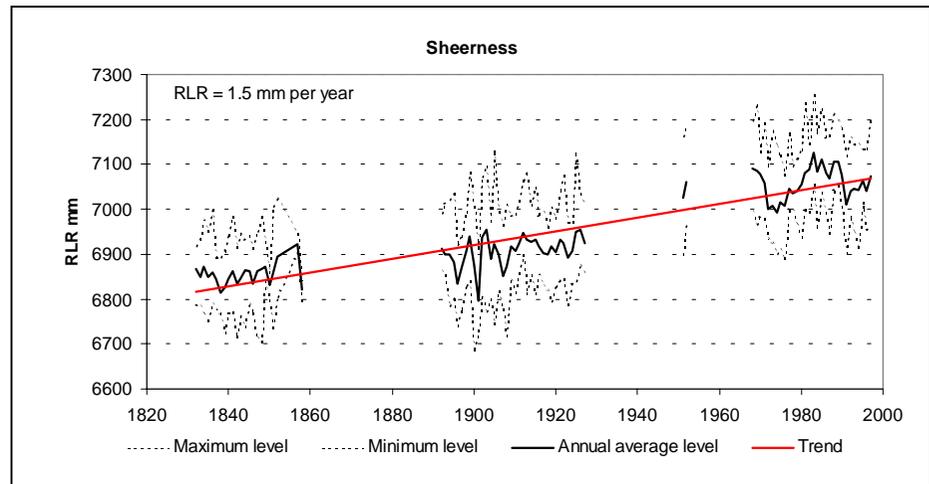


Figure 2.4e: Historic rates of sea level rise on the Kent coast.

Table 2.4a: Return periods (years) for temperature and rainfall values that are unusual in the present climate. The anomaly is relative to the present climate.

| Return Period (Years) | Present Climate | 2020s | 2050s | 2080s |
|---|-----------------|-------|---------------------------|---------------------------|
| Temperature | | | | |
| Annual: Anomaly +1.06°C as in 1997 | 17 | 2 | Almost every year exceeds | Almost every year exceeds |
| Seasonal: Anomaly +2.0°C as in summer 1995 | 50 | 3 | Almost every year exceeds | Almost every year exceeds |
| Monthly: anomaly +3.4°C as in August 1997 | 50 | 7 | 3 | 2.5 |
| Rain | | | | |
| Wet winter: 160% of normal | 17 | 4 | 5 | 3 |
| Dry summer: with less than 50% of normal rainfall | 100 | 14 | 8 | 10 |

Table 2.4b: Climate change risks, adaptive capacity and integrated vulnerability for key themes.

| Theme | Risks | Adaptive capacity | Vulnerability |
|--|--|---|--|
| Coastal management - Holding the Line? | HIGH Sea level rise and potential changes in the frequency of storm surges increase the risk of coastal and tidal flooding. There may be more frequent overtopping of sea defences and even breaches through protective shingle banks. Coastal populations may be at risk. Coastal ecosystems such as salt marshes and mudflats may be lost. Saline incursion and intrusion. | HIGH Preventing development: the prevention of development along the coastline to reduce future costs of defences. Flood Warning: advanced real-time flood warning systems and improved flood contingency planning Flood Defence: New defences take account of sea level rise in some developed coastal areas. In other areas managed retreat becomes a more popular option, some important habitats are saved but others are lost. Changing location: Movement of industry away from the coast. | MEDIUM National and regional institutions can adapt in the long term. However there may be surprises, e.g. large storm surge events before adaptation processes are underway. Some loss of habitat inevitable. This can not be preserved but may be replaced by other valued habitat elsewhere. |
| Changing Countryside | HIGH Detrimental affects on river and wetland ecology due to lower summer rainfall and high water demands Habitat fragmentation and the lack of migration pathways for species. Summer drought particularly on thin arable soils. Increased loss of shallow rooted trees. | LOW Augmentation boreholes for supporting river flows. In some areas suitable sources may be unavailable. Creation of habitat pathways. Hedgerow and woodland conservation. Replacement of shallow rooted species with drought resistant species. | HIGH Habitats at risk from water regime and temperature changes. Conservation management thus difficult. High level of development and variable geology mean that there are limited escape routes for migrating plants and animals. |
| Water Supply - Meeting the Demand | HIGH Low summer rainfall and river flows. Uncertainty regarding fate of increased winter rainfall (recharge or runoff?) High peak demands in the summer due to domestic demands, particularly garden watering. South East already has the highest per capita demands and experienced difficulty meeting demand in 3 summers during the 1990s. Lower raw water quality from surface water and groundwater sources due to elevated sediment, bacteriological and nutrient loads from agriculture and less dilution in summer months. Also saline intrusion and incursion in coastal areas. | MEDIUM Many possibilities but need for increased awareness and capital investments. Better understanding of total supply systems, future demands and groundwater yields. “Twin track approach”: use of demand management and increased storage. New reservoirs Water transfers from north west to south east. Work towards the “zero water garden” replacing plants with drought tolerant species. Grey water recycling Further reduction in leakage: a reduction in the economic level of leakage. Investment in efficient water supply and distribution systems. | MEDIUM – HIGH Much work required on adaptation to minimise risks. Drought contingency planning and increased public awareness needed now. |

but other species, like the mole cricket and marsh gentian that prefer wetter heathland may suffer as their habitat dries out in summer.

Agricultural change will have a major impact on the countryside. Farmers are concerned about securing adequate water supplies and the risk of drought in summer. There will be opportunities for growing new crops such as sunflowers and soya beans on the southern margins of Hampshire and West and East Sussex (Carter, 1991, Holloway *et al.*, 1997). Changing climate, river flow regimes and agricultural production techniques could lead to deterioration of some of the region's high quality chalk streams. Increased summer temperatures, lower summer river flows and higher nutrient and sediment loads due to more intense storms are all factors that favour eutrophication in surface waters.

2.4.4 Emerging issues: what's new!

Many climate impacts on the environment are well known (at least in qualitative terms) but impacts in two areas have received less attention in recent years. First, the impacts on society and the economy of climate change are more difficult to quantify than environmental impacts. Secondly, the integrated impacts across different sectors are not always fully explored. These two issues are discussed in more detail here.

Economic impacts

The South East England study team discussed possible impacts with many key businesses in the region but the responses were highly variable. The main problems were:

- The short planning horizons of small to medium size enterprises (SMEs);
- The relative (perceived) unimportance of climate factors to some businesses compared to social or economic change;
- The lack of understanding of the effect of climate factors on business costs e.g. direct links like air conditioning and heating as well as indirect affects like transport problems caused by severe climate or climate related illness.

The second point was addressed by UKCIP by developing a set of non-climate futures (Berkhout *et al.*, 1999). We had the opportunity of discussing the relative importance of climate versus non-climate effects with some stakeholders and have attempted to summarise the results in Table 2.4c.

An interesting insight gained during the study was that SMEs that rely on water supplies are vulnerable to climate change. For example:

"A change from groundwater to surface water abstraction imposes costs on paper production"

Table 2.4c: Stakeholders' view of vulnerability to socio-economic and climate impacts (by economic sector)

| | | | |
|---|------|--|---|
| Vulnerability to socio-economic change | HIGH | Services Tourism Manufacturing Health | Paper manufacturing NGOs Local Authorities Brewing Insurance Agriculture |
| | LOW | Oil Pharmaceuticals Biotechnology Energy | Water Ports |
| | | LOW | HIGH |
| Vulnerability to climate change impacts | | | |

at our plant of 1-2% due to the salinity of our surface water source. This cost change would mean loss of business to companies in the North (UK and further N. Europe) who will have advantages if their resources are not scarce". (Paper manufacturer).

Other industries such as breweries, agricultural enterprises and institutions such as local authorities and NGOs also perceive their operations or interests to be at risk from climate change and, in many cases, feel they have limited capacity to adapt to the changes.

Businesses are mobile and in a scenario where water costs rise or quality falls they may relocate elsewhere or simply lose out compared to competitors in a more favourable location. While movement of industry away from South East England may be seen as acceptable (or desirable) from a national perspective, it is clearly a concern for regional development agencies.

Integrated impacts

Another emerging issue is the need to gain an understanding of the integrated impacts of climate change and various within-sector adaptation measures. The example of water catchment quality is presented here.

- River flows in the South East of England are likely to increase by around 15% in winter but decrease by around 18% in summer.
- Demand management measures, such as recycling, will reduce return flows from water works in the summer months.
- 'New' crops and changes to soil microbial activity will lead to changes in nutrient cycling.
- Existing storm water storage designs do not take climate change into account so there may be more polluted sewer overflows.
- There will be less water for dilution which will mean higher concentrations of nutrients.
- Increased temperatures will favour weed and algal growth.

Each of the impacts is known in isolation, but the combined effect of all these changes have

yet to be estimated. Together, they may result in a serious deterioration in water quality and a change in the biological quality of some of the regions valued chalk streams.

2.4.5 Regional adaptation: what now?

The South East England study identified a large number of impacts and benefits of climate change for the region. In order to manage these changes and make the best of new opportunities the report identified four general themes to support adaptation responses. These are summarised in Table 2.4d with some examples from our three main impact areas.

2.4.6 Research priorities

Although adaptation strategies can not wait for the results of new research findings, there are still a number of areas where additional research would benefit ongoing adaptation responses. The following areas are of particular relevance for South East England.

Economic and planning

- Climate impacts and adaptation in high per capita GDP sectors, particularly the service industry SMEs;
- Regional land use planning models that consider possible climate and non-climate futures and the interactions between them.

Water

- Integrated catchment studies that consider water balance, water quality and ecological change;
- Changes in domestic, industrial and agricultural demands in a changing climate;
- Water efficiency and grey water recycling;
- Environment Impacts Assessment of effluent re-use;

Table 2.4d Example adaptation responses to manage climate impacts by response type for countryside management, meeting water demands and coastal zone management.

| | Changing countryside | Meeting the Demand | Coastal management |
|----------------------------|--|--|---|
| Raising Awareness | Education on potential losses and changes due to climate change | “Water wise campaigns” – garden watering | Flood awareness – making people who live in tidal floodplains aware of the risks |
| Monitoring | Changes in species composition Habitat area and degree of fragmentation | Monitoring components of water use within households to improve per capita consumption estimates | Beach erosion, wave energy and coastal evolution monitoring with remote sensing and real-time monitoring equipment |
| Integrated planning | Consider need for habitat corridors as well as flood risk in planning proposals | Consider the ability to meet the demand of new households Review need for new reservoirs Water companies as statutory consultees | Considering the full environmental costs and benefits of flood defence including heritage and ecological interests |
| Risk management | Understanding extreme event impacts on agriculture and ecological change Ensure that there are no early losses of valued species that could remain or migrate | Drought contingency planning and emergency response tools Outage contingency planning | Do not rely on historical data to estimate areas vulnerable to tidal flooding – develop improved approaches to floodplain mapping |

- Flexible consenting – new ways of managing the water abstractions and discharges in a changing environment.

recharge: guidelines for resource assessment. Environment Agency Technical Report R&D W82.

Environmental management

- Ecological responses and changes in biodiversity. How to manage a changing countryside?
- Future of South East England’s Ramsar sites and SPAs;
- Extreme events;
- Downscaling of future climates and weather generation to examine the impacts of extreme events;
- Extreme events and valuation of their costs in urban environments.

Berkhout, F., *et al.* (1999). *Non-Climate Futures Study. Socio-Economic Scenarios for Climate Impacts Assessment. Final Report.* SPRU, 20th October 1999.

Carter, T. R., Parry, M.L. and Porter, J.H. (1991). Climatic change and future agroclimatic potential in Europe. *International Journal of Climatology* **11**: 251-69.

Hulme, M. and Jenkins, G., 1998. *Climate Change Scenarios for the United Kingdom. Technical Report. UK Climate Impacts Programme Technical Report No. 1.* Sept. 1998, 80pp..

2.4.7 References

Arnell, N., Reynard, N., King, R., Prudhomme, C. and Branson, J. (1997). *Effects of climate change on river flows and groundwater*

Holloway, L. E. and Ilbery, B.W. (1997). *Global warming and Navy beans: Decision*

making by farmers and food companies in the UK. *Journal of Rural Studies* **13**(3): 343-355.

Wade, S.D., Hossell, J. and Hough, M. (eds.) (1999). *The Impacts of Climate Change in the South East Technical Report*, WS Atkins, Epsom, 100pp.

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2.5 South West England¹

Kylie J. Russell²

2.5.1 Introduction

Climate change will affect all sectors of the UK, and different regions will be affected in different ways. The economic profile and distinctive geography of South West England, with its exceptionally high quality natural environment and extensive and exposed coastline, mean that effects here may be very different from those in other regions of the UK. Organisations in South West England recognised that there was a need to develop a better understanding of how climate change would affect them, and how they ought to respond to this global issue at a regional level.

Collaboration between the In Pursuit of Excellence Initiative, the Universities of Plymouth and Exeter, Plymouth Marine Laboratory, the Duchy of Cornwall, the Environment Agency and UKCIP led to the formation of a Steering Group and the organisation of the Climatic Challenge Conference. The aim of this conference was to initiate a process that would provide regional decision-makers with the necessary information to prepare for the changes ahead. A researcher was employed to produce a 'Strategic Summary of Climate, Environment and the Economy in the South West of England'. This paper highlighted the uniqueness of South West England in order to make initial assessments of sectors of the region that may be particularly vulnerable to changes in climate. Information was collated from the Office of National Statistics, the Environment Agency, water companies and numerous economic studies from within the region. Indicators from this report as well as national research and experience from past weather events, which could become more common in future, suggested the types of impacts that might be experienced in South West England. Section

2.5.2 explores some of the outputs from these studies.

2.5.2 Main specific findings on vulnerability sectors and places

The South West England climate plays an important role in a number of business sectors in the region such as agriculture, fisheries and tourism. However, climate and extreme weather events are also important in many less obvious sectors such as the insurance industry, retail and manufacturing. Clearly any changes in climate, which affect the quality of the natural environment and associated economic activities, will have substantial implications for South West England.

The South West of England is the largest English region, representing 10% of the UK land cover; however, it has the lowest population density of any English region with almost 5 million people, half of which live in rural areas. The region covers an area of ca.24,000km² and much of this landscape is recognised nationally, with 26% of the region designated as 'Areas of Outstanding Natural Beauty'. This is double the proportion found in England as a whole. The region also includes 850 sites of Special Scientific Interest (21% of England's SSSIs) and the National Parks of Dartmoor and Exmoor, 2 of only 7 in England. In addition, the region includes the World Heritage Sites of Stonehenge, Avebury and the City of Bath, over 6,000 Ancient Monuments, that is 37% of the total for England, and over 100,000 individual listed buildings.

¹ A full report on the conference proceedings can be obtained from the following website: www.climatic-challenge.org.uk

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Another unique quality of South West England is its high sea to land ratio with its extensive varied and attractive coastline. This coastline is also recognised as an important asset with over 630 kilometres designated as Heritage Coast (more than 60% of the total for England). South West England also contains nearly half the UK's EU designated bathing waters. Its environment also makes an important contribution to the economy. Environment related economic activity contributes ca.100,000 jobs and £1.6 billion to the region. Overall the value of the environment is approximately 5-10% of the region's total GDP and contributes to over 4% of employment.

Tourism and leisure

- In 1996, 21.7 million tourists visited South West England. In 1997, spending was equivalent to 10% of GDP in the region.
- Tourism supports ca. 11 000 businesses and ca. 150,000 jobs.
- There is accommodation for ca. 600,000 in more than 10,000 establishments. There are around 800 tourist attractions.
- Over 80% of visitors to the region travel by car.
- Between 1991 and 1996, tourist numbers increased by 21%. Continued growth is forecast for the future.

Climate change could bring many benefits to regional tourism. A longer, more reliable, summer season is likely to increase spend and may encourage more domestic holidaymakers. There may be a greater emphasis on outdoor and water-related recreation. Such growth would create jobs, encourage business opportunities for small and medium sized enterprises (SMEs), boost the regional economy and may also provide opportunities for diversifying the industry in areas currently less well developed.

Set against these benefits are a number of challenges. Certain tourist attractions could be directly affected by climate change. For example, historic gardens and parks may be vulnerable to changes in soil moisture, temperature and humidity, and those in coastal areas could be threatened by sea level rise. Higher tourist numbers would increase pressures on services and utilities, particularly

in terms of water supply and treatment, waste management, emergency services, health care and transportation. Visitor pressures in the regions' many high quality natural environments will need to be carefully managed to minimise impacts on sites.

Health and demography

- The population of South West England is one of the lowest in the UK. This is expected to grow by nearly 11% between 1996 and 2016 with the number of households increasing by almost 25%.
- There is a relatively high proportion of older people and a large proportion of people live in rural areas.
- Allowing for the age structure of the population, the region has the lowest mortality rates in the UK.

National research has shown that climate change could increase summer death rates if the frequency of intensely hot spells increases. This could be very important for South West England given its large aged population which is most vulnerable to such conditions. Heatwaves are also most likely to coincide with the peak holiday season. Past heatwaves have typically resulted in higher mortality rates from drowning.

Indirect impacts on health could be numerous. If periods of peak demand coincide with higher temperatures and reduced precipitation, water quality could suffer. Disinfection systems operated by water companies may need to be enhanced to cope with poorer water quality, to ensure that the incidence of waterborne gastrointestinal infections does not increase. Warmer sea temperatures could increase populations of marine biotoxins, and lead in turn to increased risk of shellfish poisoning. Incidents of respiratory diseases may increase, as hotter summers could promote the production of photochemical pollutants (e.g. ozone). Certain diseases (e.g. Lyme disease) present in South West England could become more prevalent in a generally warmer climate.

Agriculture and land use

- Agriculture is of greater importance to the region than it is nationally, accounting for 13% of businesses, almost 4% of GDP and employing 2.1% of the workforce.

- More than 80% of land cover is agricultural and over half of this is long standing grassland used for livestock.
- The region has 31% of the Environmentally Sensitive Area (ESA) agreements in England.
- There is a trend towards diversification in agriculture to other forms of income such as tourism to improve profitability.

Impacts on agriculture and land use will be critical in South West England, given the exceptionally high quality of its natural environment. Benefits to agriculture include carbon dioxide (CO₂) fertilisation, a longer growing season, and opportunities to grow novel crops such as grapevine, maize, soya bean and sunflower. But milder, wetter winters are likely to favour pests and diseases; warmer, drier summers may increase irrigation needs or call for the cultivation of drought tolerant varieties; higher summer temperatures will increase the risk of heat stress to poultry and other livestock; and intense rainfall may increase risks of crop damage and soil erosion, and reduce water quality. Areas such as the Isles of Scilly and the Somerset Levels are particularly susceptible to flood risk due to sea level rises and agriculture here is especially vulnerable.

Utilities, infrastructure and buildings

- 80% of the region's water is abstracted from surface water resources, the remainder from below ground. Demand for water is higher during the summer and tourism exacerbates this.
- Amounts of sewage sludge produced are predicted to almost double by 2005.
- The distance travelled per person per year by car is the second highest for any region, reflecting the rural nature of the region. Roads are more congested in the summer.
- Air travel and activity at major ports is increasing. Smaller ports, especially those associated with fishing are in decline.

Changes in water availability, storminess, extreme weather and energy use associated with climate changes are expected to present key challenges to the region. The transport infrastructure may be exposed to an increased risk of flooding and damage, particularly in

coastal areas, due to rising sea levels and increased storminess, and higher summer temperatures could increase risks of road rutting and buckling of railway tracks. Energy consumption patterns are likely to alter, with implications for producers. The water sector may face similar changes in water demand and supply: more variable precipitation may disrupt water supplies, and high costs may be incurred in meeting demand, particularly in areas dependent on surface water supplies. The construction industry is likely to be affected by more frequent or severe extreme weather events (such as hot, dry, subsidence-inducing conditions, driving rain and windstorms) and building materials and design may need to be altered to accommodate growing demand for more energy efficient buildings. Increases in tourism will put additional pressures on transport, water and the disposal of waste.

Business, finance and insurance

- In 1999, there were ca. 220,000 VAT registered businesses in South West England, just over 9% of the UK total.
- Businesses tend to be small, with 85.2% employing fewer than 10 people and only 2.5% employing more than 50 people.
- The motor trades, wholesale / retail, hotels and catering industries account for the largest number of all business sites in the region (some 31%) reflecting the heavy dependence on the tourist industry.

The implications of climate change for business and insurance are numerous. Markets for new products are likely to emerge. For example, higher summer temperatures may increase the need for air conditioning in workplaces and for cooling equipment in the chemicals, food and beverage industries. Similarly, demand for hot weather consumables may increase. However, warmer winters are likely to reduce the need for space heating and cold-weather equipment. More frequent extreme weather could adversely affect markets as retail supply chains are typically geared towards average conditions.

Insurers may be hard hit by climate change. While milder winters may result in fewer cold-weather claims, warmer summers could generate a greater number of subsidence-related claims. Possible changes in the frequency and intensity of extreme weather events such as droughts,

floods and storms could prove very costly for the industry as a whole.

Coastal and fisheries resources

- South West England is a peninsula with a long coastline. Over 630km have been designated as Heritage Coast. There are 450km of estuary and sea defences. There are 185 designated bathing beaches (over 40% of the national total).
- The region has the largest fishing fleet and the highest level of landings by value in England. Half of all shellfish waters in England and Wales are in the region.
- Approximately 90% of the fish landed are exported from the region, leading to a high dependency on road and ferry links.
- As water temperatures rise, more southern species are appearing in South West England waters.

Of major significance to South West England are potential impacts on its coastal and marine resources. Rising sea levels and increased storminess are likely to increase rates of coastal erosion. Natural assets in the coastal zone may be lost and areas of saline intrusion will increase, particularly in low-lying coastal areas. Many beaches too, may be 'squeezed' by rising sea levels, which could threaten their viability – particularly those which are only exposed at low tide. Managers of areas vulnerable to sea level rise will face stark choices on how to manage those sites in future.

Significant impacts can be expected on fisheries. Rising global temperatures are likely to reduce the overall productivity of the oceans, affecting species across the entire marine food chain. Such changes would exacerbate current pressures on fish stocks, and would have serious consequences for fisheries in South West England which are so important to the local economy.

2.5.3 Key climate change issues for South West England

A set of climate change scenarios was developed specifically for the Climatic Challenge Conference by Dr Mike Hulme of the University of East Anglia (UEA), that explore how the climate of the region will be

affected by climate change. These scenarios examine the relevant information for South West England that can be extracted from the UKCIP98 national climate change scenarios. The study also included an analysis of recent changes in climate within the region as well as a comparison of the UKCIP98 scenarios produced using the Global Climate Model (GCM) with scenarios produced by a Regional Climate Model (RCM).

Past climate

The longest temperature series in South West England is found in Plymouth where records have been kept since 1874. This record shows a warming trend of about 0.3°C per century, with 3 of the 4 warmest years occurring in the last decade (1989, 1990 and 1995). Plymouth experiences on average only between 3 and 4 'hot' days per year (days with maximum temperature over 25°C), but in the last 20 years, four summers have recorded over 10 'hot' days each - 1976, 1983, 1989 and 1995.

The regional precipitation series for South West England and South Wales shows that summer precipitation has fallen by up to 20% since the late 1800s. There has been a slight compensating increase in winter precipitation with the 3 wettest winters on record all occurring in the last decade - 1989/90, 1993/94 and 1994/95. Sea-level measurements from Newlyn since 1915 show a sea-level rise of about 17 cm per century. When these measurements are adjusted to account for natural rates of subsidence of the land, the net unexplained change in sea-level for Newlyn is a rise of between 3 and 10 cm per century.

Climate change scenarios

The rate of future climate warming in South West England for the four UKCIP98 scenarios is between 1.0°C and 2.9°C per century. Under the UKCIP98 medium-high scenario, 'hot' summers that presently occur once a decade may occur 70% of the time by the 2050s and the one-in-ten 'cold' winter virtually disappears in the future. The summer of 1995 was the second warmest recorded at Plymouth with an anomaly of 2.4°C above the 1961-90 average. This summer warmth equates to the average summer to be expected by the late 2050s under the medium-high climate scenario. An extreme summer, however, by the 2050s will be considerably warmer than this. The winter of 1989/90 was the

mildest ever recorded at Plymouth and was 2.2°C warmer than the 1961-90 average. By the 2050s, about half of all winters for the medium-high scenario will be at least as mild as this, but some individual winters will be much milder still.

Winter precipitation over South West England is predicted to increase by between 7% and 15% by the 2050s, whereas summer precipitation remains unchanged or decreases by up to about 10% by the same period. 'Dry' summers that presently occur once a decade may double in frequency by the 2080s, whereas 'wet' winters become three times more frequent than at present. The UKCIP98 scenarios also suggest that daily precipitation intensities will increase, most notably in winter. Thus, as well as experiencing wetter winters, the region may expect to see more of this increased winter precipitation falling in more intense storm events than at present. Future rises in average sea level for South West England due to global warming range between 12cm and 67cm by the 2050s. A further 6 to 12cm would need to be added to account for the naturally subsiding coasts of the peninsula.

Regional Climate Model (RCM)

A comparison of outputs from the Hadley Centre's RCM with the GCM used to produce the UKCIP98 scenarios has been completed. The RCM has a spatial resolution of 50km, which allows South West England to be resolved by seven model land gridboxes as compared to only one gridbox in the UKCIP98 scenarios. The most important conclusion found by this study was that the scenarios for South West England based on a high resolution RCM were not fundamentally different from scenarios based on the companion GCM. Therefore, the UKCIP scenarios presented were found still to be valid.

2.5.4 Review of the institutional structure for the study

The Climatic Challenge Conference, held at St. Mellion, Cornwall on October 28th–29th 1999, brought leading figures in the climate change research community together with representatives from national and regional government, the European Union, non-

governmental organisations and a wide range of business interests. There were six workshops held at the conference: Coastal and Fisheries Resources; Demography and Health; Agriculture and Land Use; Leisure and Tourism; Utilities and Infrastructure; and Business, Finance and Insurance. The aim of these workshops was to identify impacts and opportunities for economic development in South West England associated with climate change and the environment.

In parallel a web-based 'Virtual Conference' was run in order for the conference to be more accessible to SMEs and members of the public. The web site provided a cumulative record of the conference and a window into its proceedings. It contained information about the scope of the conference and its sponsors and partners, statements from key personnel, press cuttings, briefing papers and case studies and provided opportunities for interaction. At the conclusion of the St. Mellion event, summaries of the conference papers and workshops reports were added to the site. By the end of January 2000, the web site had been visited 684 times.

The web site was designed to encourage active participation. In order to broaden the debate on climatic change in South West England, an interactive area was launched on the web site at the end of September 1999. This offered people an opportunity to enter into discussion about some of the major issues. To facilitate discussion, a number of key questions were posted in the discussion area for each of the themes. Entry to the discussion was through freely available on-line registration and passwords.

As a follow-up to the conference a number of workshops were run between February and March 2000 for SMEs within the region. The aims of the workshops were to consider the effects of extreme climate events in the region and provide the latest scientific information on predicted climate change in South West England. They also aimed to identify business planning issues associated with future climate changes and identify information needs of the business sectors in order to inform future research programmes.

2.5.5 Key findings during stakeholder consultation

Stakeholder consultation was through workshops at the Climatic Challenge Conference, through the Virtual Conference discussion site and through follow up workshops for SMEs. A common theme to emerge from each of the economic sectors addressed was the need for further information on how changes in climate impact on the region's environment. It was felt that any opportunities for economic growth in South West England should be sustainable and not in any way impinge on the natural environment. Businesses felt that the environment was one of the region's most important commodities and that any deterioration of it would be detrimental to the economy of the region.

Stakeholders within the Health and Demography Sector felt that the impacts of climate change within the region would be much less severe than in other areas of the world. It was thought that the worst impacts were likely to be felt outside Europe, particularly in the Third World and that the public health and socio-economic infrastructure within South West England should be able to reduce the adverse effects on health. However, some impacts were still likely and further research was needed into these.

Within the Agriculture and Land Use Sector it was thought that the role of agriculture as a positive component in the reduction of greenhouse gas emissions through the capture (and in the case of forestry, long term retention) of carbon dioxide needed to be recognised. It was also thought that despite the variety of positive and negative implications for agriculture in the region, in general, climate change should not cause serious problems. This is because the changes will occur gradually over decades, and modern farming has shown admirable ability to adapt to new circumstances. Furthermore, land use and production patterns consistent with the expected warmer, wetter winters and hotter, drier summers are evident in farming systems already practised further south in Europe, providing a predictable guide to the production adjustments to be expected. The diversification

of farmers into other areas such as tourism as a consequence of climate change was also noted.

The Coastal and Fisheries Sector highlighted a number of important issues for South West England. Flooding of coastal areas with sea level rise was of particular concern, as was the continued erosion of cliffs and beaches. Erosion of beaches may have important impacts on tourism in the area. The remobilisation of metalliferous mine and industrial wastes due to storms and increased winter rainfall could have potential impacts on fisheries (larvae) and bathing water quality. It was thought that fishermen would adapt to changes in fish species around South West England, however, reductions in the overall productivity of the oceans would exacerbate current pressures on fish stocks.

The Utilities and Infrastructure Sector recognised that an increasing population in South West England may lead to additional pressures on water and waste infrastructure as well as on the road network in the region. It was noted that increased visitor numbers would exacerbate these pressures. Forecast trends in climate have important implications for utilities and infrastructure (water, sewerage, electricity, healthcare, transport and communications). The problems are that planning presently has too short a timeframe (2-5 years instead of 20-50 years) and plans are not linked in a way that facilitates proper co-ordination. There was a recommendation for the formation of a Regional Inter-Utility Climate Change Discussion Group.

Within the Business, Finance and Insurance Sector it was considered important that businesses adapt to changes in the environment and in world markets and those that were able to adapt were most likely to survive. Within business planning a two year plan is rare and a twenty year plan is unreal; in addition, environmental considerations currently come well down the list. There was thought to be a need for information on good practice, e.g. examples of successful environmental adaptation that has brought speedy economic benefit.

All aspects of the Leisure and Tourism Sector were thought to be heavily affected by global warming leading to a possible boost to outdoor leisure activities and coastal tourism. Tourism is seeing a change to an increased demand for short breaks, activity holidays and self-catering options

and a warmer climate was not expected to reverse these general trends. There was also a perceived need for investment in quality leisure and tourism facilities to tap into the possibility of increased demand. A constraint that needs to be addressed is the issue that most tourists currently travel to the region by road. That will become more expensive with government policies to reduce vehicle emissions. Rail services to Devon and Cornwall were perceived to be poor and in need of improvement to compensate for the increased cost of road travel.

2.5.6 Main recommendations for responses/adaptation

Agriculture and land use

The South West of England should take a lead in showing how land use and the rural economy should develop in response to climate change. Initiatives should be defined, examined and put in place by responsible bodies. Awareness of the options and most likely directions for agricultural change should be widely promulgated, and enterprising farmers/landowners should be encouraged to capitalise on the positive opportunities that climate change presents, in order to serve as leading indicators for others.

Business, finance and insurance

Businesses need to take up the opportunities presented in terms of the provision of climate change services, environmental consulting, the provision and installation of technological solutions, construction, and the provision of retail and services associated with lifestyle changes. High value-added, low space demand industry should be encouraged and inward investment should build on the existing strengths of the region. There may be opportunities in information technology and homeworking as well as in the provision of private health care services due to the ageing demography of the population.

Coastal and fisheries resources

Climate change might bring opportunities for artificial reefs for surfing and diving as well as for recreational fisheries for exotic southern

species (tuna, great white sharks). There should be further investment in research into offshore renewable energy sources, such as wind and wave energy, and a reassessment should be made of the environmental and economic effects of the Severn Barrage. More accurate measurements are required of land level subsidence to improve the models for rise in sea level. There should be further research into the erosion of coasts and beaches as a careful balance will be needed between protecting certain assets and retreating from others where costs of sustaining coastal defences or replenishing beach become uneconomic. There was a perceived need to rationalise the current split in responsibilities for flood and coastal defence and work towards more integrated management.

Utilities and infrastructure

A new ethic is required at the household level to reduce waste and use water more efficiently. More reservoirs may be required, however, these are a resource in their own right, providing a habitat, site for water sports and a tourist attraction. The use of renewable power should be encouraged including using waste to produce power and encouragement of Combined Heat and Power schemes. The setting up of an 'Alternative Energy Committee' by the South West England Regional Development Agency (SWERDA) was suggested. Pressures will increase on the transport sector and the SWERDA should be encouraged to incorporate a plan for the transport system in their strategy. Investment by Railtrack is needed to create new lines or line doubling within the region (e.g. from Salisbury to Exeter).

Health and demography

The Department of Health has commissioned the first UK national assessment of the impacts of climate change on health (Section 3.4). Regional impact assessments are also required for developing appropriate strategies. An integrated approach to monitoring impacts (health outcomes) and exposures (e.g. air pollution, water quality) is required, with links to programmes in other countries. More research is needed on the potential health impacts of climate change, in particular, quantitative estimates of future impacts. Research will require inter-sectoral collaboration, for example, between the water, health and academic sectors.

Tourism and leisure

It is important to ensure that tourism and leisure industries benefit from the changes brought about by global warming. An increase in visitor numbers to the region will put pressures on utilities and infrastructure and may not prove beneficial to the economy if not managed efficiently. One solution would be to attempt to restrain the growth of tourism per se but to improve spend per visitor. Another suggestion was to consider the potential for eco-tourism to be promoted within the region. The extension of the holiday season was also thought to be both beneficial for the economy and for employment in the area, as was the increase in year-round activity holidays (e.g. water sports, walking, cycling and climbing).

2.5.7 Research priorities

One of the most important research priorities will be the downscaling of national climate change scenarios by extracting data-sets on the South West of England to run regional models. In addition, there needs to be an improvement in climate forecasting and past and future recording of climate variables such as the frequency and intensity of precipitation events, wind speeds, gusts, storm surges and inland flooding. These data are essential for use in risk analysis and insurance and in the design specifications of new buildings. For example; what will be the new 1 in 10 year, 1 in 50 year and 1 in 100 year storm event?

Continuous monitoring of key determinants of environmental quality (e.g. air quality, ultra-violet light, biodiversity) in relation to climate change is important and existing long-term databases need to be maintained. An improved rigour of recording is required to ensure relevance of records and to eliminate false readings.

Research into renewable energy and energy efficiency may lead to business opportunities for the region. For example, opportunities exist within the region for production of energy from waste and 'Hot Rocks', for wave and tidal energy and for wind turbines (including offshore wind farms). There could be a promotion of Combined Heat and Power schemes within the region and the use of more

efficient building materials (e.g. cob) and zero emission building design.

A number of socio-economic models looking at the links between climate change and a number of sectors within the region may prove beneficial. For example, modelling the capacity of the utilities within South West England to cope with increased demand due to climate change. The model could include factors such as waste treatment and collection and sewage sludge production and disposal as well as changes in energy usage and transport infrastructure.

Knowledge of the relationship between climate change and water resources will be vital for a number of sectors. A model needs to be developed investigating the likely changes in demand due to increasing tourism, population, agricultural requirements and higher temperatures. Climate change impacts on groundwater recharge and surface water flows would need to be studied in order to assess their effects on water resource availability. The model could include water quality issues such as increased leaching of pollutants during high rainfall, concentration of pollutants in rivers during low flows and increases in algal blooms. Issues such as inland flooding caused by more rapid run-off and the exacerbation of this by agricultural policy, deforestation, development, short intense precipitation events and less summer rainfall would also be important.

More information is required on the complex relationship between climate and tourism. This includes investigations into how these factors have been related in the past as well as in areas that have climates similar to those predicted for the South West in the future. The South West England tourist industry requires information on whether climate change will lead to a longer season as well as information on changes in the demography and disposable income of tourists to the region. Research into ways in which eco-tourism in the region could be promoted could also be beneficial.

The coastal zone is particularly important for South West England and there is a vital need for further monitoring and research of coastal erosion and defence within the region. As beaches make a substantial contribution to the regional economy, research into the movement of sand to ensure the maintenance of beaches is

essential. Assessing the risk of remobilisation of toxic substances (e.g. heavy metals) in riverine/estuarine sediments is also important.

It is crucial that research is undertaken in South West England to determine how best agriculture and natural resources can be managed to cope with climate change. Important issues include whether climate change will lead to the loss of the region's competitive advantage over other regions and which new crops will be viable in the future. Will the amount of grazing land for livestock decrease due to poor grass growth and how will this impact on the appearance of the region? Research into the socio-economic implications for the rural economy and its population is also a major priority.

More research is needed on the potential health impacts of climate change, in particular, quantitative estimates of future impacts. Research questions include: How fast people will acclimatise to the warmer climate? What will be the changes in life-expectancy due to heatwaves? What are the risks of the introduction of 'new' diseases? How will adaptation to climate change, for example, increased use of insecticides, affect health? Research into the effects of air pollution in the region on respiratory problems was also thought to be a priority.

2.5.8 Centre for Climate Change Impact Forecasting (C-CLIF)

At the conclusion of the Climatic Challenge Conference the establishment of a new Centre for Climate Change Impact Forecasting (C-CLIF) was announced. It is intended that C-CLIF will address a number of the research priorities recommended by stakeholders throughout the Climatic Challenge project. The centre is the result of collaboration between the Universities of Plymouth and Exeter, and the Centre for Coastal and Marine Sciences (Plymouth Marine Laboratory). The new centre will be an interdisciplinary research centre to study climate change and its consequences for society, the economy and the environment in South West England. It will be a centre for research, a focus of expertise for consultancy, a repository and source of data and information accessible to the utilities, agencies and small

businesses alike. C-CLIF will conduct academic research on the one hand while providing the regional economy with expert knowledge to help adapt to climate change and its consequences. Initially C-CLIF will concentrate on scaling down national scenarios by extracting regional data-sets to run regional models. The new centre will have a commitment to provide an authoritative and politically neutral source of expertise for the media and public.

Chapter 3

Reports on Sectoral Studies

Introduction

3.1 DETR/MAFF biodiversity review and the SNH environmental audit

Jo Hossell

3.2 REGIS: Regional climate change impact and response studies in East Anglia and North West England

Peter Loveland, Eric Audsley, Pamela Berry, Terry Dawson, Anton De Baets, Paula Harrison, Ian Holman, Robert Nicholls, Mark Rounsevell, Janet Sells, Simon Shackley, Theresa Wilson and Robert Wood

3.3 MONARCH: Modelling natural resource responses to climate change

Terry Dawson, Graham Austin, Pamela Berry, Barnaby Briggs, Humphrey Crick, Paula Harrison, Jo Hossell, Mark Rehfisch, Alison Riding and Heather Viles

3.4 Health effects of climate change in the UK

Robert Maynard and Megan Gawith

3.5 Review of external projects using the UKCIP98 climate scenarios

Iain Brown

Introduction

This section presents a series of contributed papers on the current sectoral studies that come under the UKCIP umbrella. Biodiversity features strongly in these studies, as national organisations have realised its vulnerability and the need for further research. Hence, both Scottish Natural Heritage (SNH) and DETR/MAFF have commissioned studies intended to better inform policy on climate change impacts: these are reviewed together in Section 3.1. The SNH study pre-dated the UKCIP98 scenarios, but is included here because of collaboration between SNH and UKCIP, and because the methodology has links with the DETR/MAFF review. The MONARCH study (Section 3.3) provides a different approach to ascertaining likely impacts on UK biodiversity, incorporating detailed spatial modelling.

The REGIS study (Section 3.2) also employs a modelling approach, but is distinctively cross-sectoral, and is intended to provide a regional methodology for integrated impacts research. A link between the REGIS and MONARCH projects is provided by the common use of the SPECIES biodiversity model. Conclusive results are not available yet from these two studies as work is still in progress. The emphasis in these sections is therefore on methodology, but early results are suggesting that these studies will break significant new ground.

A sectoral review of health issues is presented in Section 3.4, based on work that is currently underway by an expert review for the Department of Health. Key health impacts from sub-UK scoping studies completed within the UKCIP framework are also presented.

The final section in this chapter (Section 3.5) presents a review of other sectoral studies that have been initiated within the past 3 years using the UKCIP98 climate change scenarios. Whilst these projects have not been commissioned by the UKCIP, their use of the UKCIP98 scenarios will enable results from these studies to be compared with other UKCIP studies, and their findings will help inform the debate on what further climate change impacts work is needed.

Methodological issues emerging from all of these studies are discussed in more detail in Chapter 4.

3.1 DETR/MAFF biodiversity review and SNH environmental audit

Jo Hossell¹

3.1.1 Introduction

This section discusses two recent studies of the implications of climate change for biodiversity. The first is the ongoing DETR/MAFF-funded review of the impact on UK conservation policy and the second the Scottish Natural Heritage-(SNH) funded environmental audit for Scotland (Hill *et al.*, 1999)

3.1.2 Review of climate change implications for UK conservation policy

Study context and objectives

This DETR/MAFF-funded project (DETR code CC0223, MAFF project number BD1107), which started in February 1999, seeks to identify those species and habitats most at risk from climate change impacts. Both the direct and indirect effects of climate change were considered. The UK government is bound by a range of national and international obligations to protect key species and habitats. The project aims to highlight how the implications of climate change for habitats, species and networks of conservation importance could affect these current commitments at both a policy and practical implementation level. The work takes into account the range of different organisations and agencies involved in conservation within the UK and provides recommendations on the timing and nature of adaptations that will be needed to adjust to climate change impacts.

The key project objectives are:

- To review climate change impacts on species, habitats and networks, the

wider countryside, and current policy commitments;

- To recommend prioritised research and an early detection system;
- To consider and outline policy responses and a framework for implementing those policies.

Institutional structure of the study

The study has been supported by a steering group consisting of the key conservation institutions and agencies within the UK. This has allowed the project to consider both conservation policy and agri-environment and forestry policy implications of climate change. The recommendations will cover this wide range of policy areas and institutions.

Study methods and output

The project has used several different approaches to gather the information needed to assess the vulnerability of species and habitats in the UK to climate change. Initially, a literature review was undertaken to determine how much information was in the public domain about habitat and species responses. The study adopted the Biodiversity Action Plan (BAP) Broad and Priority Habitats as its basic framework. Published, unpublished and draft papers from climate change impact studies, work on current trends, and some studies on ecological theory were reviewed to determine the sensitivity of habitats and species. Over 200 references were consulted and where possible the review related the projected changes to the four UKCIP98 climate scenarios (Hulme and Jenkins, 1998).

The study faced the difficulty that most of the published information on climate change and habitats was published before the BAP

¹ ADAS, Wolverhampton

framework was developed. Hence studies of climate change impacts do not always define their subject matter in the same habitat groupings. In addition there have been fewer studies of the effects of climate change on species and habitats in the UK than on land use or land cover types, such as agriculture. The project therefore also consulted experts to extend the information review.

A workshop was held in June 1999 to discuss the vulnerability of UK species and habitats to climate change. Experts from a range of academic and environmental organisations were invited. The discussion focused on the direct and indirect effects of climate change on habitats.

A summary of the review findings on the effects of climate change by broad habitat type will be included in the final project report. In addition, a more complete literature review, incorporating a discussion of the information sources and the means used to assess climate change impacts will be made available.

The information gathered from the workshop and literature review has been used to develop a series of vulnerability matrices. Tables have been drawn up to include key indirect and direct impact drivers (e.g. increased frequency of drought) and to show the sensitivity and effect of these drivers on BAP priority habitats and species. The source of the information has also been identified at a general level (e.g. literature review, workshop, project team expert opinion). Further evaluation matrices on the importance of the broad habitats in the UK and international context and on measures currently in place to assist adaptation to climate change impacts have also been developed. Finally, a summary table, ranking the broad habitats by their vulnerability to climate change, has been created.

The main purpose of the matrices is to enable straightforward identification of species and habitats likely to suffer adverse effects from climate change and identification of the particular aspects of climate change which are responsible. The tables also make it easier to identify those species for which effective responses can be readily planned. Finally, they indicate gaps in existing knowledge about the

likely impacts of climate change for protected habitats and species.

The evaluation matrix was used at the second project workshop in September 1999, which discussed the effects of climate change on current conservation policy. This meeting was attended by a range of policy experts from the UK. It aimed to highlight the steps needed to allow conservation policy to adapt to climate change impacts.

Key habitat vulnerability

One of the key findings of the study will be the identification of particular habitats that are most vulnerable to climate change. This assessment has considered not just the impact of climate change *per se*, but also the extent of changes to policy or conservation practice that will be needed to adapt to these impacts. Preliminary results suggest that the most vulnerable BAP broad habitats will include:

- Montane, both arctic and sub-arctic;
- Bogs, particularly lowland raised bogs;
- Chalk rivers;
- Soft-sediment coastal habitats such as dunes and machair.

Some montane habitats, in particular may have 'no place to go' under a warmer climate, whilst the others could suffer from a mixture of habitat loss, restricted migration potential and change in species composition.

However, not all habitats and species will be detrimentally affected by climate change. Elements of the more southerly distributed communities may be expected to expand in the future and the conservation status of currently rare species in these areas may improve.

Policy implications

Current conservation policies and commitments have developed over a number of years and include a mix of national legislation, international agreements and EU directives. A major issue is the degree to which existing commitments may be difficult to attain because of climate change impacts. This affects both 'site-based' conservation

policies and policies for biodiversity in the wider countryside.

This may be illustrated by the so-called ‘Snowdon Lily’ scenario, in which climatic conditions may no longer be suitable for the survival of a species or habitat. In the case of the Snowdon lily, *Lloydia serotina*, the potential loss from its sole native UK locality could be taken as a failure to meet commitments under the UK BAP. However, these failures may be mitigated if successful relocation is achieved in one or more localities that become climatically suitable for the species – montane sites in Scotland for example.

For international commitments much depends upon interpretation of international agreements, such the term ‘favourable conservation status’ in the EC Habitats Directive. If appropriate attention is given to developing realistic guidelines to assist in assessing ‘conservation status’, taking account of the dynamics of natural habitats and the implications of climate change on the distribution of habitats, then problems of interpretation may be avoided. However, the ultimate arbiter would be the European Court of Justice (ECJ), and no such cases have yet been brought.

A key restriction in responding to climate change is the availability of land suitable to support species of conservation concern and the restricted ability of species and habitats to migrate as climate change occurs, due to the fragmentation of many semi-natural habitats in the UK. For this reason, conservation policies for the wider countryside may become more important in the future. Schemes that allow a co-ordinated response across areas may be most efficient, since they could also facilitate migration of less mobile species. However, improved connectivity could also promote the spread of some less desirable invasive species.

Further research needs

The study is also considering requirements for further research. For example, some coastal habitats, although well studied in terms of the impact of sea-level rise, are less well understood in terms of the effects of

temperature and rainfall changes on the flora and fauna.

A key requirement is the need to monitor the extent and rate of changes in habitats of conservation importance. A number of monitoring exercises and surveys are already undertaken on a regular basis across the UK, but there are some gaps and a need for better co-ordination. For example, complete and consistent information on the distribution of the BAP habitats across the UK is not currently available.

The final report of this study is in preparation and is expected to be published later in the year.

3.1.3 Climate changes and Scotland’s natural heritage: an environmental audit

Introduction

This SNH-funded study aimed to assist in the understanding of the potential consequences of climate change for Scotland’s natural heritage, so that future strategies and advice could take account of the effects.

Study context and objectives

The study objectives were:

- to produce an audit report on the likely consequences of climate change for Scotland’s animals and plants;
- to identify possible indicators of climate change in Scotland;
- to list data-sets and research programmes relating to the effects of climate change on Scotland’s natural heritage;
- to produce a summary overview of key issues.

The study took as its framework the ‘pressure, state, response’ model. As the study started before the publication of the UKCIP98 scenarios, the ‘pressures’ were defined by the climate scenarios of the Meteorological Office’s HadCM2 general circulation model using the IPCC IS92a emissions scenarios.

The 'state' was defined as the habitats present in Scotland and identified under UK BAP and the EU Habitats Directive and the species as those on the Short and Middle BAP lists.

Study methods

The report presents data on the past and present climate of Scotland and uses spatial analogues to illustrate the potential future climate of 2050. This makes use of Canonical Correspondence Analysis (Carey *et al.*, 1995) to identify statistically 10km squares whose current climate closely matches the future climate of sites in Scotland based on: July and January mean temperature; summer (July and August) precipitation; and annual precipitation. Where existing species and habitats also occur in the analogue future climate squares, the assumption is made that climate change may have little effect on the persistence of that species/habitat. Expert opinion was also used to assess the impact of climate change in areas without a climatic analogy.

The study also proposed possible responses to the climate change effects described and it collated relevant information sources that could be used to monitor and indicate responses to climate change.

Key findings

Scaling of the HadCM2 medium sensitivity scenario provides a projected average annual

temperature increase of 1.8°C by 2050 and a 15% increase in annual precipitation. The increase in rainfall is expected to be greatest in autumn, with little increment in summer.

The report usefully identifies those aspects of climate change for which confidence is highest (Table 3.1a). It recommends that greatest credence be given to projections where confidence in the magnitude of the driving force is highest.

The report provides tables in the appendices listing the habitats and species included in the study, and an indication for each of the potential effect of climate change. For habitats the main findings were:

- Alpine and sub-alpine habitats and species are considered to be at risk from the rise in temperature and change in snow frequency and persistence. This may have a negative effect on populations of mountain birds, such as ptarmigan (*Lagopus mutus*), dotterel (*Charadrius morinellus*) and snow bunting (*Plectrophenax nivalis*).
- Habitats on soft coasts may be expected to migrate in-land where coastal defences allow, but some habitats such as dunes and saltmarsh may be lost if migration is inhibited.
- For forest habitats, the effects of increased temperatures and higher

Table 3.1a: Confidence in the major predicted effects of climate change

| Climatic element | Confidence | Effects |
|-----------------------------------|-------------------|---|
| Carbon dioxide (CO ₂) | Very high | Increased photosynthesis and reduced water use by plants; unclear effects at the ecosystem level |
| Sea-level rise | Very high | Loss of land or of intertidal zone if coast is protected |
| Temperature | High | Accelerated growth; longer and earlier growing season; potential range expansion northward and to higher elevations; reduced frost and winter die-back; higher potential evapotranspiration |
| Precipitation | Low | Increased run-off and leaching; increased growth of drought-sensitive cryptogams; increased snowfall when temperature is below freezing |
| Storminess | Very low | Increased windthrow and soil erosion; reduced infiltration of rainfall |
| Variability | Very low | Potential changes in the risk of damaging events (heat waves, frost, drought, floods) |

atmospheric CO₂ were considered to be beneficial to tree growth.

- Undamaged raised and blanket bogs would continue to grow under climate change.

The effects were often considered to be beneficial to species, with bats and insects potentially benefiting from increased temperatures. Lichens and bryophytes with oceanic distributions are expected to increase their range in Scotland, though possibly at the expense of Eastern lichen populations. Montane bryophytes, in common with most species of this habitat, are expected to be at greatest risk and may be lost entirely from Scotland.

The study also examined the impact of climate change for near-shore marine habitats and species, though changes to sea surface temperatures were not considered and the projected changes were based on the proximity of species to their northern or southern margins in Scottish waters. For the northern species such as the white-sided dolphin (*Lagenorhynchus acutus*) and the white-beaked dolphin (*Lagenorhynchus albirostris*) some northward shift of distribution may be expected, but for other species the impact is considered to be neutral or beneficial.

Recommendations for responses/adaptations

The study considers briefly the current measures in place to mitigate the effects of climate change but concludes that despite this action, adaptation will be necessary to cope with the impacts of climate change for natural resources. However, the findings are relatively optimistic that most of the species on the UK Biodiversity Group's Priority List will have a neutral or positive response to climate change. Nevertheless, the question of whether it is worth continuing to save arctic-alpine species was raised.

Some consideration is given to the implications for conservation policy but more emphasis is given to changes in practical management that may be needed. Possible responses and adaptations that may be adopted range from maintenance of existing habitats

and species mixes by grazing, to habitat creation and translocation. The final conclusions, phrased as a series of questions, describe what further information is needed to allow conservation policy and practice actively to encompass the impacts of climate change. They are:

- Which habitats can be managed to maintain their condition under climate change?
- Which habitats should be allowed to undergo natural succession or change as a result of climate change?
- Is it worth attempting to save arctic-alpine species given that change will continue beyond 2100?
- Are there opportunities for habitat creation and for managed retreat in particular?
- Where will it be practical to control competitors?
- What opportunities are there for translocation?
- Is there adequate monitoring in place to ensure that effects of global change are observed in time to undertake mitigating action?

3.1.4 References

Carey, P.D., Preston, C.D., Hill, M.O., Usher, M.B. and Wright, S.M. (1995). An environmentally defined biogeographic zonation of Scotland designed to reflect species distributions. *Journal of Ecology*, **83**: 833-845

Hill, M.O., Downing, T.E., Berry, P.M., Coppins, B.J., Hammond, P.S., Marquiss, M., Roy, D.B., Telfer, M.G. and Welch, D. (1999). *Climate changes and Scotland's natural heritage: an environmental audit*. Scottish Natural Heritage Research Survey and Monitoring Report No. 132.

Hulme, M. and Jenkins, G.J., (1998). Climate change scenarios for the UK: UKCIP Technical Report No. 1, Climatic Research Unit, Norwich. 80pp.

3.2 REGIS: Regional climate change impact and response studies in East Anglia and North West England

Peter Loveland¹, Eric Audsley, Pamela Berry, Terry Dawson, Anton De Baets, Paula Harrison, Ian Holman, Robert Nicholls, Mark Rounsevell, Janet Sells, Simon Shackley, Theresa Wilson and Robert Wood.

3.2.1 Introduction

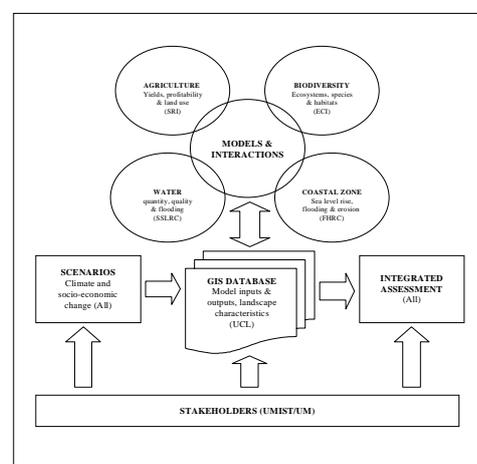
The main purpose of the REGIS project (MAFF project number CC0337) is to evaluate the *integrated* impacts of climate change on the agriculture, hydrology, biodiversity, and coastal areas of East Anglia and North West England. These two areas are representative of the diverse landscapes, climates and land-uses of England and Wales, e.g. East Anglia is a low-lying area of largely intensive arable agriculture, experiencing low rainfall, and with extensive stretches of coasts backed by relatively soft sediments. North West England is cooler, hillier and wetter, with agriculture dominated by grassland.

It is not possible to predict the future, only to postulate reasonable scenarios, and investigate their implications. Therefore, like most other projects of this kind, REGIS centres on *sectoral models* of climate change impacts derived either from substantial previous research, or developed for this project. Modelling of this kind also requires spatially-referenced data built from both stakeholder inputs and existing scientific sources. Thus, the work has the following main objectives:

- To produce a methodology which can be used by other stakeholders and similar interest groups to address the same kinds of questions elsewhere in the UK.
- To compile a geographically-referenced database (GIS) for the two regions containing environmental data, climate change scenarios and socio-economic change scenarios.

- To adapt, calibrate and validate models of agriculture, water resources, biodiversity and coastal zones, which can be used to assess the impacts of climate change.
- To involve regional experts, decision-makers and other ‘stakeholders’ in the design of the assessment, for example through the identification of critical impacts, interactions and adaptive responses.
- To explore climate change impacts for three future time periods: 2020, 2050 and 2080.
- To investigate the potential effects of climate change on critical impacts and their interactions, using linked models and scientific expertise.
- To analyse the range of possible adaptive responses and the influence of future policy and socio-economic scenarios upon the response.
- To work with stakeholders to communicate the findings to the appropriate policy and lay audiences.

The funding for the REGIS project, provided



¹ Soil Survey and Land Research Centre, Cranfield University.

Figure 3.2a: The REGIS integrated model

by MAFF, DETR and UK Water Industries Research (UKWIR) totals £300,000.

3.2.2 Methodology

The framework within which the REGIS project is conceived is illustrated in Figure 3.2a. Sectoral models have traditionally been regarded as independent components, largely because each sector is of most concern to specific groups, e.g. crop yields have been dealt with by agricultural research, water resources by climatologists and hydrologists, biodiversity issues by ecologists and so on. However, it is also clear that if, for example, climate change will alter the pattern, intensity and amount of rainfall, then this can be expected to affect crop yields, water demand for irrigation or domestic use, conservation of habitats and a large number of other issues. Choices could well have to be made on the basis of interactions rather than stand-alone impacts. For example, greater water abstraction for public supplies may result in an increased incidence of low flows in rivers, which will impact directly on abstraction for irrigation. Either of these could threaten a wetland habitat, and a decision would be needed as to priorities, especially if, for example, some or all of the wetland species are protected by statute.

3.2.3 The database

The first part of the methodology involved collecting data for the two regions, and placing these in a geo-referenced database. The decision was made to geo-reference all data components to a regular 5km grid, so that the modelling can be undertaken to a common spatial format (Figure 3.2b).



Figure 3.2b: REGIS study regions

The general concept behind the GIS was to construct a single ARCVIEW project containing all the necessary scripts (ARCVIEW programmes) for data query and manipulation. A user can then add different themes (i.e. specific data types) and attribute tables for these themes, as required, from the range of data made available within a defined directory structure. Five categories of data have been incorporated into the GIS:

- Topography;
- Land cover;
- Soils;
- Climate and climate change scenarios;
- Administrative boundaries and coastline.

These data are required either as inputs to the various linked REGIS models, or as potential sources of data for model validation and testing. The ARCVIEW project can be saved with different filenames to reflect the changed contents of the project. Legends, titles, colours, etc. can be edited according to specific requirements or preferences. This approach allows the GIS to be customised for different purposes. For example, a specific set of data may be required for different model runs, but only a subset of the database may be required for presentation to the stakeholders. Particular developments within the ARCVIEW project, include:

- Automatic querying of the soils data at specified locations.
- Soil depth restriction for arable cultivation (according to a user-specified depth) added automatically as an attribute value.
- 10km resolution climate data, provided by the Climate Research Unit at the University of East Anglia (UEA), imported into the ARCVIEW project automatically.
- The final project has been produced on a CD. The GIS also provides an appropriate framework for the analysis of the model outputs that will be produced during the course of the REGIS project. Many such outputs are being added as REGIS progresses. This facilitates analysis and visualisation of the model results. In addition, further data can be incorporated

as they become available from the project modellers.

- The GIS is a generic product which can accept input for other regions, so long as the file format structure is adhered to.

3.2.4 The models

These have been taken from existing sources or have been created specifically for the project:

- ACCESS (Agroclimatic Change and European Soil Suitability) (Loveland and Rounsevell, 1996), which is a soil-crop-atmosphere water balance model.
- IMPEL (Integrated Model for Predicting European Landuse) (Rounsevell, 1999), which integrates crop modelling into a socio-economic framework.
- SFARMOD (Audsley, 1993), which is a socio-economic farm-scale management model.
- SWATCATCH (Surface Water Attenuation of Pesticides in Catchments) (Hollis and Brown, 1996), which predicts flows and solute concentrations at catchment outlets.
- SPECIES (Spatial Estimator of the Climate Impacts on the Envelope of Species) (Berry, Dawson and Harrison, *pers. comm.*) uses a neural network to integrate biophysical variables for characterising habitat microclimates. It has been developed specifically for this project.
- A coastal flood risk model (Nicholls and Wilson, *pers. comm.*) developed specifically for this project.

Much of the preliminary work in the modelling has centred on the following:

- SFARMOD's handling of grazing and livestock has been improved, with a more complex model of animal feeding within the arable farming systems.
- Irrigation and irrigated crops have been incorporated within both ACCESS and SFARMOD models, to provide input to the water quality models.

- A farmer's perception of risk has been included within SFARMOD, in order to improve the cropping output results.
- SWANCATCH has been integrated with the output from ACCESS/IMPEL.
- The SPECIES model has been trained on European data.
- A linkage mechanism has been developed for the integrated model runs.
- The criteria for coastal flood risk assessment have been established, and a model framework built to accommodate these.

3.2.5 The stakeholders

A number of workshops, and face-to-face and telephone interviews have been held with stakeholders in both regions. The key findings to date are that:

- Climate change is accepted as reasonably certain at the regional scale.
- The impact of climate change upon water resources is the major issue in both regions.
- At the local level, biodiversity and coastal zone impacts are also critical.
- There is a high knowledge of regional policy mechanisms and initiatives for inclusion of climate change impacts.
- Climate change is perceived as an issue which should be integrated into existing policy mechanisms, rather than being tackled through entirely new ones.
- Impacts are rarely discussed independently of responses.
- Greater consistency and certainty was called for in scientific information on climate change and its impacts.

More recently, stakeholders have been engaged in dialogue with REGIS team members in order to link socio-economic scenarios with climate change scenarios. A report on the stakeholder consultation work has been prepared and is available (Shackley and Wood, 1999).

3.2.6 Model output

Introduction

The modelling undertaken so far has been to test the models, the data, and the database. Although this is not integrated modelling, it is very necessary to ensure that the components work reliably and to throw up any abnormalities. The results themselves are not without interest.

Water resources (from SWANCATCH/IMPEL)

Figure 3.2c shows the relationship between the modelled prediction of *total* groundwater resource and the published data (supplied by the Environment Agency) for East Anglia.

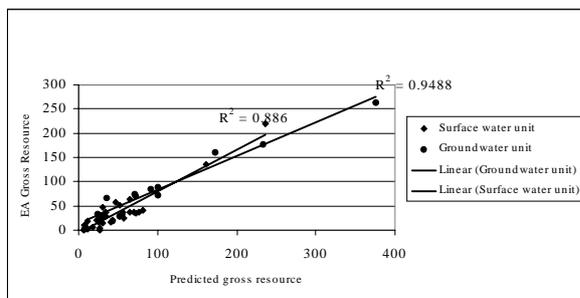


Figure 3.2c: Comparison of REGIS predictions and Environment Agency (Anglian Region) assessments of gross groundwater resource (000's cubic metres per day).

Biodiversity (from SPECIES)

Figure 3.2d shows preliminary results of the SPECIES modelling for the distribution of dwarf willow.

Agricultural change (from SFARMOD / IMPEL)

Figure 3.2e shows the correspondence between actual and modelled areas of winter wheat in East Anglia.

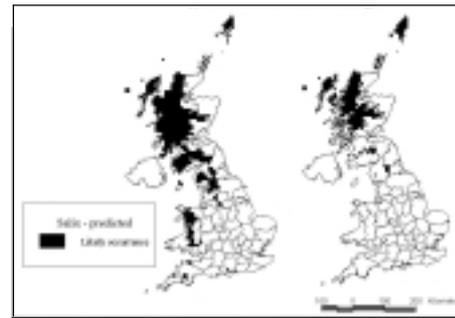


Figure 3.2d: Could this be the changing distribution of *Salix Herbacea*? Preliminary results from the SPECIES model of distributions for the current climate (left-hand map) and the 2050 UKCIP98 high climate change scenario (right-hand map).

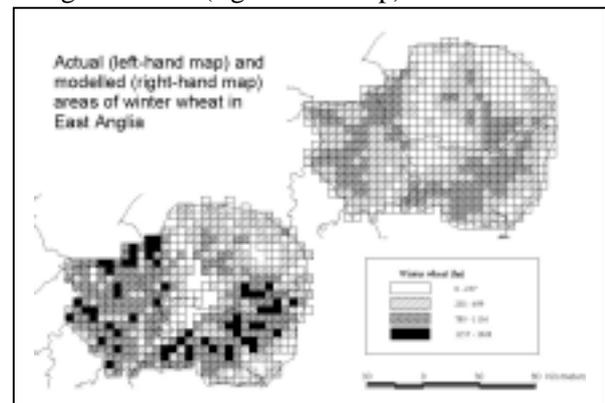


Figure 3.2e: Actual (left-hand map) and preliminary model results (right-hand map) showing areas of winter wheat in East Anglia.

3.2.7 Integrated modelling

There are two aspects to the modelling. First, the individual models have been modified so as to accept common file formats and outputs from each other, and to deliver outputs to a standard format. Part of this exercise has involved testing for errors within the data, precise definitions of parameters, and refinement of the computing code to ensure efficient running of the models. The stage is now set for the first integrated model run. The schema for this is given in Figure 3.2f. Secondly, we have had to choose between the very large number of potential model runs possible within the framework of UKCIP

climate scenarios. With the assistance of major stakeholders, and using work carried out by the

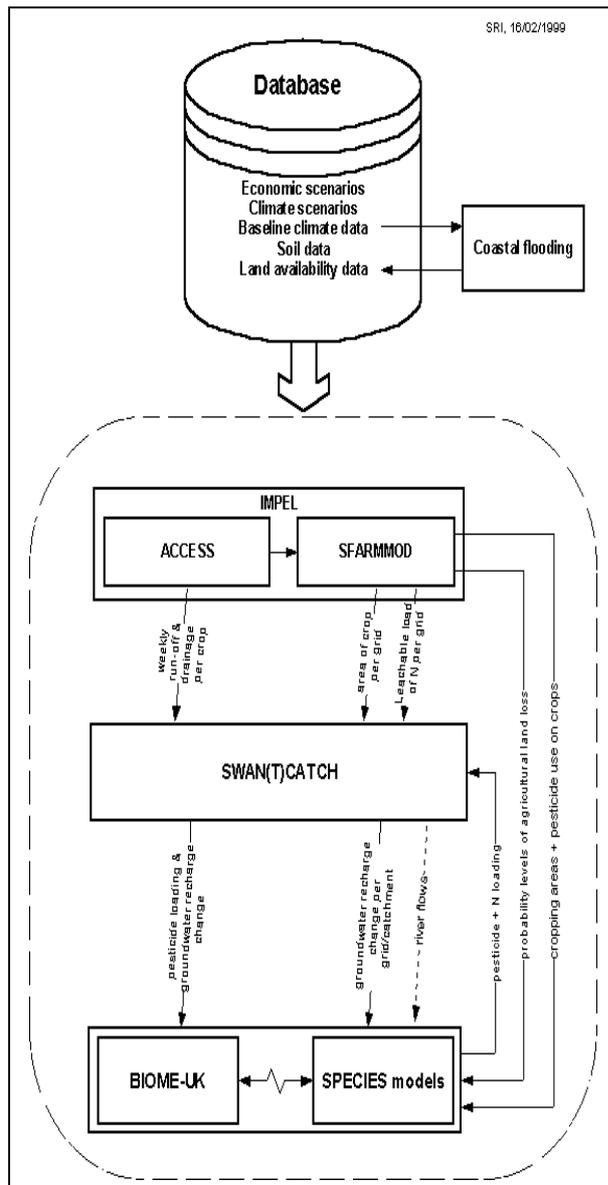


Figure 3.2f: Integrated model run framework

Science Policy Research Unit (SPRU) at the University of Sussex, we have chosen the following as the preliminary integrated runs, in the following order:

- Baseline (1961-90) conditions: this is to give a baseline for comparison with the 'futures'.
- UKCIP 2050-High climate scenario with current socio-economic conditions: this to give the highest climate effect.

- UKCIP 2050-Low climate scenario with current socio-economic conditions: this to give the lowest climate effect.
- UKCIP 2050-High climate scenario with socio-economic inputs based on Regional Enterprise (derived from the National Enterprise scenario).
- UKCIP 2050-Low climate scenario with socio-economic inputs based on Global Sustainability.

The last two runs are designed to illustrate the effects of maximum differences in socio-economic frameworks which could be reasonably expected within the two regions. The output from these model runs will be used to decide the nature of further integrated model runs, following a second Workshop with major stakeholders

3.2.8 The project so far

REGIS is novel in that it is the first major attempt to model climate change impacts, interaction, adaptations and socio-economic change across sectors on a regional basis. Not surprisingly, this process has identified gaps in knowledge and understanding, which may indicate the need for future research. Perhaps the biggest problems are:

- Data - both in terms of needing rapid access to a wide range of data and having them in common formats. Much of the work in the first year of REGIS has been spent in addressing this problem, whether it be climate data, altitude data, species data and so on. With time it is hoped that fewer and fewer projects will need to go through this exercise.
- The need for further work on the intelligent downscaling of climate data, as more pressure is evident on the provision of information at appropriate local scales.
- Uncertainty about extreme events, especially for droughts and flooding; this uncertainty has made it very difficult to deal with river flooding at a catchment, or indeed regional scale.
- The large measure of uncertainty about socio-economic parameters *in numerical terms*, and how these can be linked to

climate change scenarios with greater confidence.

3.2.9 References

Audsley, E. (1993). *Labour, machinery and cropping planning. Proceedings XXV CIOSTA CIGR V Congress*. Farm planning. Labour and labour conditions. Computers in agricultural management edited by Annevelink, E., Oving, R.K. and Vos, H.W. Wageningen, Netherlands; Wageningen, pp. 83-88.

Hollis, J.M. and Brown, C.D. (1996). A catchment scale model for pesticides in surface waters. In: A.A.M. del Re, E. Capri, S.P. Evans, and M. Trevisan (Eds.) *The Environmental Fate of Xenobiotics, Proceedings of the X Symposium Pesticide Chemistry, September 30 - October 2 1996, Castelnuovo Fogliani, Piacenza, Italia, La Goliardica Pavese, Pavia, Italy*, pp. 371- 379.

Loveland, P.J. and Rounsevell, M.D.A. (1996). *EuroACCESS: Agroclimatic Change and European Soil Suitability*, SSLRC, Cranfield University, Silsoe, UK, 234 pp.

Rounsevell, M.D.A. (1999). *Spatial modelling of the response and adaptation of soils and land use systems to climate change - an integrated model to predict European land use (IMPEL), Volume 2*, SSLRC, Cranfield University, Silsoe, UK, 249 pp.

Shackley, S. and Wood, R. (1999) *REGIS Project, Stakeholder Involvement, Working paper 1*, unpublished, Manchester, 74pp.

3.3 MONARCH: Modelling natural resource responses to climate change

Terry Dawson¹, Graham Austin, Pamela Berry, Barnaby Briggs, Humphrey Crick, Paula Harrison, Jo Hossell, Mark Rehfisch, Alison Riding and Heather Viles

3.3.1 Introduction

The MONARCH project is an important first step towards understanding the complex interactions between climate change and nature conservation. It covers both the UK and Republic of Ireland, since species are not delimited by country boundaries, and it is important to unite information sources and work within naturally-defined areas. The study aims to evaluate the impacts of climate change on the natural conservation resources of the British Isles through an integrated methodology linking established impact models to coherent climatological zones, determined by a statistical analysis of bioclimatic variables. The study will evaluate impacts on a broad range of species (including plants, birds and reptiles), habitats and geological features (including limestone caves and outcrops) in diverse environments.

3.3.2 Natural resource response to climate change

The UK and Ireland governments have a range of European and national commitments to habitat and species conservation and enhancement of biodiversity. English Nature, in conjunction with the other environmental agencies and non-governmental groups funding this work are involved in implementing conservation policies such as Biodiversity Action Plans. However, currently these conservation commitments do not take into account the potential impacts of climate change.

In working at the national level, consideration must be given to the inherent spatial patterns of the features being examined. This is particularly important when considering the

effect of non-climatic features such as soils, geology and geomorphology on the distribution of nature conservation resources. However, impact study results need also to be expressed at the national level for policy formulation and administrative regions for policy implementation. It is necessary, therefore, to devise a classification scheme, which can encompass these scales and allow information to be aggregated in a systematic and meaningful way.

It is recognised that this work will form an important first step in identifying the direct impacts of climate change on biodiversity and geological features in Britain and Ireland.

3.3.3 Methodologies and preliminary results

A bioclimatic classification of the British Isles

The effect of climate on animals and plants arises out of a set of complex interactions between the total range of climatic elements. However, for classification purposes it is necessary to reduce these variables down to a manageable number. Factor analysis (especially principal components analysis - PCA) is being used objectively to select variables to explain the greatest climatic variation across an area (Gregory, 1975). Principal components analysis has been used in previous studies to define zones of similar climates across Europe and the UK (e.g. Gregory, 1975; White, 1981; Jones and Bunce, 1985; Orr and Brignall, 1995).

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A bioclimatic PCA has been undertaken using the climatic variables listed in Table 3.3a (100 in total). The analysis produced eight principal components, which represent independent new variables that account for more than 97% of the variation across the data-set. Examination of the variables (Table 3.3b) related to the components shows that the first factor accounts for the variability in most of the precipitation and moisture variables (61.64%), factor 2 the temperature and growing season length variables (18.35%) and factor 3 the wind speed variables (7.79%). Figure 3.3a shows the spatial distribution of annual Growing Degree Days (GDD) above 5°C for the British Isles, which was one of the bioclimatic input variables used in the PCA analysis.

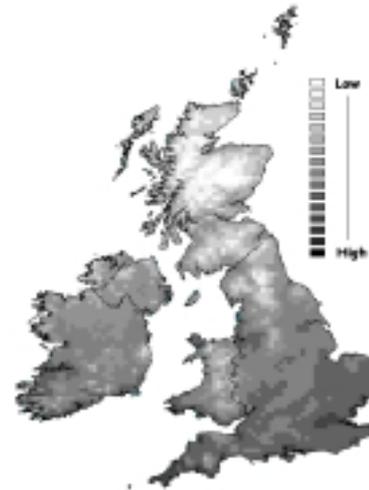


Figure 3.3a: A spatial map of Growing Degree Days (GDD) above 5°C for the British Isles (ECI, 2000).

Table 3.3a: Bioclimatic variables used in the PCA.

| Variable name | Unit of measurement | Temporal resolution |
|---|---------------------------|---------------------|
| Accumulated temperature (GDD) | > 5°C | Annual average |
| Maximum temperature of hottest month | °C | Annual average |
| Minimum monthly temperature | °C | Monthly |
| May – June rainfall total (bird nesting period) | mm | Annual average |
| Potential Evapotranspiration (PET) | mm | Monthly |
| Mean monthly temperature | °C | Monthly |
| Absolute maximum temperature | °C | Annual average |
| Absolute minimum temperature | °C | Annual average |
| Raindays | No. of days | Monthly |
| Monthly rainfall total | mm | Monthly |
| Wind speed | ms ⁻¹ | Monthly |
| Rainfall - PET | mm | Monthly |
| Sunshine hours | hours month ⁻¹ | Monthly |

Table 3.3b: Variables relating to the first four PCA factors.

| Variable name | Factor 1 | Factor 2 | Factor 3 | Factor 4 |
|-------------------------------|-----------|-------------------------|-----------|-------------------------|
| Accumulated temperature (GDD) | | GDD | | |
| Absolute maximum temperature | | | | |
| Absolute minimum temperature | | Amin | | |
| Minimum monthly temperature | | Jan - Dec | | |
| May – June rainfall total | Sumppt | | | |
| Monthly rainfall total | Jan - Dec | | | Jan - Mar, May – Dec |
| PET | | Feb - Apr, Oct | | Jun – Aug |
| Wind speed | | | Jan - Dec | |
| Raindays | | | | |
| Sunshine hours | | | | Jun – Oct |
| Rainfall - PET | Jan - Dec | | | |
| Mean monthly temperature | | Jan - May, Oct - Dec | | |

The first three principal components of the analysis (accounting for 86% of the total bioclimate variation) were used in an unsupervised clustering technique. When clusters which covered less than 1% of the total area were discarded, 22 significant bioclimate clusters remained. These will be characterised in terms of their natural resources and will form the basis for the selection of species for modelling.

Geological and geomorphological vulnerability

It is recognised that some species and habitats are not currently restricted by climate but rather by geological and geomorphological features. Many of these features will not change significantly in form over the time scale used in this study, especially those based on a resistant geology. They will, however, be affected by changing rates of weathering and erosion. The former may be important for the dissolution of limestone, while the latter will be particularly significant for coastal areas. The MONARCH project has focused upon karst and four types of coastal areas (sand dunes, salt marshes, shingle coasts and rocky coastal platforms) for further study and to investigate their sensitivity to climate change through changes in geomorphological processes.

Karst is a term given to landforms produced mainly by solutional processes. Within Britain and Ireland, such landforms are mainly developed on limestone, although they can also develop in other soluble rocks, such as gypsum and rock salt. Typical landforms within karst areas are:

- large-scale: cave systems, poljes (large closed depressions);
- medium-scale: limestone pavements, gorges, dry valleys;
- small scale: tufas, cave deposits (such as speleothem), dolines.

Many of these landforms, especially the larger scale ones, have formed over thousands to millions of years. However, many small features (such as tufas and speleothem) are very sensitive to changes in the geomorphological

process-regime over the 10 to 100 year timescale. Investigations of the likely impact of future climate change must consider the impact of anthropogenic threats, such as quarrying, groundwater pollution and acid deposition, coupled with alterations in air temperatures, rainfall regimes and higher carbon dioxide levels, and focus on particularly sensitive karst landforms and landscapes.

Impacts of sea level rise on coastal habitats

The ESCAPE model, as used in the Scottish Natural Heritage Environmental Audit (Hill *et al.*, 1999), was applied to calculate the relative sea level rise for Britain. Estimates of sea level rise from the UKCIP scenarios were substituted in the model in order to ensure consistency of data usage within the project. Data on vertical land movements were obtained for the North Sea region (Shennan, 1987) and for Great Britain (Shennan, 1989). The results conform with the widely accepted models of crustal deformation caused by ice unloading and recently have been correlated with tide gauge data (Shennan and Woodworth, 1992).

These rates of vertical land movement are assumed to be constant between the scenario dates. The relative sea level rise was calculated by adding predicted sea level rise to vertical land movement for each grid cell (Figure 3.3b).

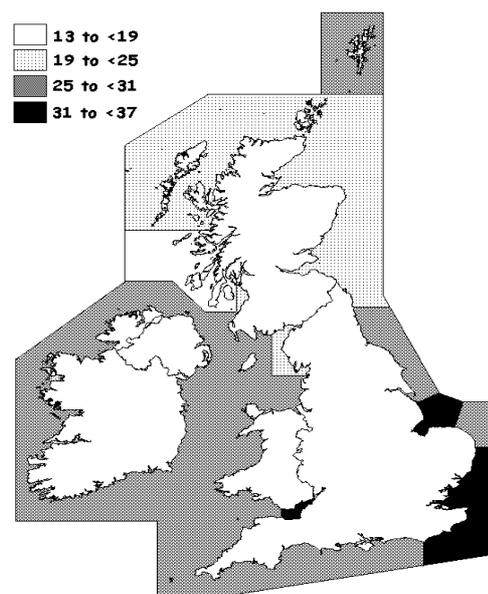


Figure 3.3b: Results from the ESCAPE model showing net change in mean sea level (cm) for the UKCIP medium-high scenario for 2050 (ECI, 2000).

Coastal vulnerability was assessed using a matrix which assigns a grid cell a vulnerability rating based on its character, evolutionary trend and degree of protection. Six coastline types, three evolutionary trends and two coastal defence codes (natural/protected) were identified.

This generates 29 unique sets of coastline descriptions and these were further simplified into five classes in order to obtain an index of coastal vulnerability (Tables 3.3c and 3.3d). The relative sea level rise and vulnerability index maps are important in indicating the areas where coastal habitats and geomorphological features are at risk. They will also be used in combination with the bioclimatic zonations, in the selection of estuaries for modelling bird populations.

Table 3.3c: Coastline types

| Type code | Description |
|-----------|----------------------------|
| M.1a | Non-erodible rocky coasts |
| M.1b | Erodible rocky coasts |
| M.2 | Sandy beaches |
| M.3 | Mud coasts |
| M.4a | Harbours, ports, etc. |
| M.4b | Other artificial coastline |

A number of internationally important wildfowl and waders inhabiting estuaries will be affected by changes in climate and sea level. Rising sea levels will alter the sediment composition of many estuaries. The nature of the sediments affects the availability and

species composition of the invertebrate fauna which support the birds. The suitability of estuaries to waders and wildfowl is also affected by the winter severity of the climate. At a higher spatial resolution, the project is investigating impacts on the densities of key estuarine bird species using models based on estuary shape (estimated from high precision topological maps and predictions of sea level rise) and important climate variables (Austin *et al.*, 1995). High-spatial measurements of estuary morphology for each selected estuary will be estimated at 10cm height increments from zero to one metre sea level rise using remotely sensed topographic data from the Environment Agency's LIDAR system (Figure 3.3c, and see Appendix 1).



Figure 3.3c: The area that would be inundated by sea water (hatched) for an 80cm rise in sea level for the Deben estuary assuming no defence intervention (BTO, 1999). The black shaded area indicates the existing inter-tidal area.

Table 3.3d: Coastal vulnerability matrix

| Type | Defence | Very low | Low | Medium | High | Very high |
|------|-----------|-----------|-----------|-----------|---------|-----------|
| M.1a | Natural | Stable | | | | |
| M.1b | Natural | | Stable | Eroding | | |
| M.1b | Protected | Stable | Eroding | | | |
| M.2 | Natural | | | Accreting | Stable | Eroding |
| M.2 | Protected | | Accreting | Stable | Eroding | |
| M.3 | Natural | | | Accreting | Stable | Eroding |
| M.3 | Protected | | Accreting | Stable | Eroding | |
| M.4a | Protected | | | | | |
| M.4b | Protected | Accreting | Stable | Eroding | | |

Marine environment

The project is also undertaking a qualitative review for the marine environment at a coarse scale to identify important issues, indicators and make recommendations for further research. Seven priority habitats recognised in the UK Biodiversity Action Plan (chalk reefs, maerl beds, *Serpula vermicularis* beds, *Sabellaria alveolata* reefs, *Sabellaria spinulosa* reefs, *Modiolus modiolus* beds and *Lophelia pertusa* reefs) are being studied. Conceptual models are being developed to investigate their sensitivity to climate change through changes in ocean temperature and other variables.

Terrestrial and freshwater environments

Changes in climate are an important driving mechanism for altering the distribution of species and, therefore, the components of habitats. Species respond individually to climate change, resulting in totally new distributions and habitat composition. The project is investigating impacts on the geographical distribution of a wide range of species using the SPECIES model (Spatial Estimator of the Climate Impacts on the Envelope of Species) (Dawson *et al.*, 1999). The SPECIES model was developed for the REGIS project, a complementary project in the UKCIP framework. SPECIES uses a neural network to characterise the current distribution of species in Europe and to estimate their potential re-distribution under alternative climate change scenarios in the British Isles. Preliminary results for one species in Britain are shown in Figure 3.3d.

A wide geographical range of Biodiversity Action Plan habitats has been selected for further study and key and/or dominant species associated with them have been identified, including species which are endangered or especially sensitive to climate changes.

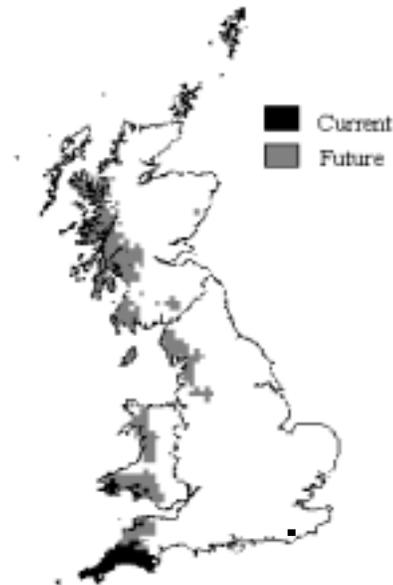


Figure 3.3d Preliminary result showing changes in the potential distribution of *Sibthorpia europaea* (Cornish Moneywort) in Britain by 2050 under the UKCIP high climate change scenario (ECI, 1999).

3.3.4 Institutional structure of the study

The MONARCH project, which started in July 1999 and will run for 18 months, is managed by the Environmental Change Institute (ECI), University of Oxford. Other consortium members are ADAS, School of Geography, University of Oxford, British Trust for Ornithology (BTO), and Environmental Resources Management (ERM). The study is being funded by a consortium of governmental and non-governmental nature conservation organisations in the British Isles, led by English Nature. These organisations recognised the need to develop their ability to forecast how climate change might impact on wildlife and geological features. The outputs of the project will help in the development of adaptation strategies and management options for vulnerable sites, will inform the determination of future research needs and policy responses, and will enhance their capacity to provide sound scientifically-based advice on the impacts of climate change on nature conservation.

3.3.5 Future research priorities

The MONARCH project has been designed to evaluate the direct impacts of climate change only. However, the intensification of a number of land uses has been an important feature of the British and Irish landscapes, and this has led to the fragmentation and loss of habitats and their associated species. It is axiomatic that land use will continue to change in the future. It will be necessary, therefore, to undertake further research to provide a better understanding of the rates and processes of land use change in managed ecosystems, and the relationships between land use and biodiversity at the regional to national scale. This will lead to an integrated approach to conservation and sustainable development, involving local stakeholders, that will identify ways of mitigating undesirable changes.

Climate change may also impact upon the rate of change of environmental processes that affect natural resources in Britain and Ireland. Under such a dynamic future, those concerned with conservation will be required to investigate alternative flexible approaches to maintaining the status of designated species, habitats and geological sites. The legal obligations involved in these responsibilities may also need to be revised.

3.3.6 References

Austin, G., Rehfisch, M.M., Clark, N.A., Austin, G., Yates, M.G., Clarke, R.T., Goss-Custard, J.D. *et al.* (1995). *Estuary, Sediments and Shorebirds III. Predicting Waterfowl Densities on Intertidal Areas*. BTO Research Report No. 160. ETSU, Oxfordshire.

Dawson, T.P., Harrison, P., Berry, P. and Pearson, R. 1999. Modelling the influence of climate change on the distribution of terrestrial biota, Abstracts, British Ecological Society Winter Meeting, University of Leeds, 20 - 22 December 1999, 55.

Gregory, S. (1975). On the delimitation of regional patterns of recent climatic fluctuations. *Weather*, **30**, 276-287.

Hill, M.O., Downing, T.E., Berry, P.M., Coppins, B.J., Hammond, P.S., Marquiss, M., Roy, D.B., Telfer, M.G. and Welch, D. (1999). *Climate Changes and Scotland's Natural Heritage: an environmental audit*. Scottish Natural Heritage Research Report, No. 132.

Jones, H. E. and Bunce, R.G.H. (1985). A preliminary classification of the climate of Europe from temperature and precipitation records. *Journal of Environmental Management*, **20**, 17-29.

Orr, J.L. and Brignall, A.P. (1995). Integration of crop model results: Methods for site and regional scale integration. In: P.A. Harrison, R.E. Butterfield and T.E. Downing (Eds.) *Climate Change and Agriculture in Europe: Assessment of Impacts and Adaptation*. Research Report No. 9, Environmental Change Institute, University of Oxford, Oxford.

Shennan, I. (1987). Holocene sea-level change in the North Sea region. In: M.J. Tooley and I. Shennan (Eds.) *Sea-level Changes*, Blackwells, Oxford, pp. 109-151.

Shennan, I. (1989). Holocene crustal movements and sea-level change in Great Britain. *Journal of Quaternary Research*, **4**, 77-90.

Shennan, I. and Woodworth, P.L. (1992). A comparison of late Holocene and twentieth century sea-level trends from the UK and North Sea region. *Geophysical Journal International*, **109**, 96-105.

White, E.J. (1981). Classification of climate in Britain. *Journal of Environmental Management*, **13**, 241-58.

3.4 Health effects of climate change in the UK

Robert L. Maynard¹ and Megan Gawith

3.4.1 Introduction

The UKCIP98 scenarios (Hulme and Jenkins, 1998) (see Section 1.2) show that the climate of the UK is likely to change significantly during the present century. Previous assessments of potential impacts of similar climatic changes on health (McMichael, 1996; CCIRG, 1996) have revealed that we may expect wide-ranging effects on human health, both direct and indirect, with some positive and other negative impacts. The precise effects of projected changes on the health of the UK have yet to be determined.

Estimating the likely health effects of altered climate is difficult because many effects arise from interactions with other factors such as air pollution, socio-economic status and the standard of health care services. The influence of climatic and weather conditions on morbidity and mortality can therefore be masked behind what are, superficially, more immediate causes of illness or death. As a consequence, many assessments to date have been qualitative in nature. However, recent developments in epidemiological research and advances in climate change scenario development have made the task, in part, feasible.

3.4.2 The UK national assessment

The Department of Health (DH) set up an Expert Group in 1999 to advise on the likely effects on health of climate change in the UK. The specific task of the Group was to determine the extent to which climate change will affect human health and to express findings quantitatively as far as possible.

Three meetings of the Group were held in 1999 at the Medical Research Council's

Institute for Environment and Health in Leicester. The expert members of the group agreed to contribute to a report setting out latest findings on key UK health issues. This report is currently in the final stages of preparation and should be published, by DH, as a consultation draft during the summer of 2000.

The Expert Group identified a number of areas of concern and investigated each in detail. Included were:

- direct effects of higher winter and summer temperatures, and of the likely increase in severe gales and floods;
- the effects of increased temperatures on the prevalence of food poisoning and vector-transmitted diseases such as malaria and tick-borne encephalitides; and
- the effects of increased exposure to ultraviolet radiation.

Some of these effects proved amenable to quantification; for others only a qualitative approach could be adopted.

The report provides a detailed list of recommendations for research. Research will certainly be needed if some of the qualitative estimates of effects are to be translated into quantitative terms. The authors focused on the likely impact on the NHS and made recommendations regarding the provision of facilities and the need for monitoring changes in the incidence and prevalence of key diseases.

It would not be appropriate to give details of the findings of the Group here – the report is not due to be published until later in the year. It may, however, be said that a number of the conclusions of the report will need to be addressed in the coming years.

¹ Senior Medical Officer, Department of Health

3.4.3 Health perspectives from UKCIP sub-UK scoping studies

Each of the sub-UK scoping studies presented in Chapter 2 considered the potential impacts that climate change would have on human health in their part of the UK. Analyses in the scoping studies were limited, with all studies drawing on previously published research and expert opinion. No original research was undertaken; instead conventional wisdom was interpreted for the area covered by the study. Nonetheless, a number of interesting findings emerged: principally the varying degree of importance attached to health as a climate change issue in the different areas. Key findings are presented briefly below.

In general, few studies viewed health as the critical climate impact issue for their location when compared with other sectors. All areas anticipated reduced winter mortality rates, relatively small increases in summer mortality, and increased risk of respiratory problems and skin cancer owing to altered exposure to allergens and sunshine. Similarly all studies identified heat stress and discomfort as important factors to consider, and noted that occupational health could be compromised by warmer summer conditions if adaptation measures are not taken. More frequent incidents of food poisoning and outbreaks of communicable diseases were also anticipated.

The North West England scoping study (Shackley *et al.*, 1998) concluded that health impacts in the region would be mixed, but that overall effects would be beneficial. Specific negative impacts identified for the region included heat stress in urban areas and amongst industrial workers, and increased respiratory problems related to more frequent pollution episodes, owing to anticipated changes in local atmospheric circulation patterns.

Positive impacts, however, included a generally healthier lifestyle as more people

engage in outdoor activities in warmer summers, and consume a better diet. Attendant commercial and social benefits of such changes were considered to outweigh possible negative impacts.

The South East England and Wales assessments concluded that human health impacts would be relatively minor compared with impacts on other sectors, such as water resources and the rural landscape (Wade *et al.*, 1999, Farrar *et al.*, 2000). While South East England currently has the lowest percentage of long-term health problems in England and Wales, specific health concerns for the future were identified in both places.

Incidence of some vector-borne diseases (eg. Lyme disease and, theoretically, malaria) is expected to increase in South East England. More importantly, several health problems could arise from changes in the region's water quality. Increased levels of cryptosporidium and other potentially harmful organisms in water sources may result from increased stormwater run-off and flooding, although the regulatory requirements upon water companies regarding water treatment and monitoring should prevent any increased incidence of waterborne disease. The effects on drinking water quality of increased frequency of algal blooms will require detailed study.

Farrar *et al.* (2000) note that the risk of cryptosporidium outbreaks in Wales could increase during droughts as well as floods, since use of water filters might need to be discontinued at times of low river flow.

A further issue of concern identified in the South East England scoping study is that exposure to pesticides in water courses and as residue in food may increase (Wade *et al.*, 1999) should greater concentrations of chemicals be needed to control pests and weeds.

Exposure to allergens may increase in both places. Wade *et al.* (1999) point out that more productive plants may produce more pollen and that hayfever may become more problematic in South East England, while Farrar *et al.* (2000) note that new forms of allergic reactions could be experienced with different flora present in the countryside,

leading to different forms of, for example, contact dermatitis.

The picture presented for Scotland and South West England is more complex, with social and economic profiles influencing vulnerability to health impacts. It is thought that primary issues for public health in Scotland will continue to revolve around socio-economic conditions (housing etc.) in future (Kerr *et al.*, 1999), and that climate change would be of relatively minor importance for public health. It was noted, however, that indirect climate change effects such as changes in housing and air quality (namely increased risk of damp and consequent respiratory illnesses), were likely to be of greater concern to health than direct effects of altered temperature and precipitation regimes.

South West England was considered to be more vulnerable to health impacts than other parts of the UK (Kovats and Bentham, 1999). Its ageing population will be vulnerable during the more frequent heatwaves anticipated in future, which are also likely to occur during the peak tourism season when visitor numbers are high. Cryptosporidiosis and Lyme disease are present in South West England and could persist in future.

Possible psychological impacts of a changing climate were identified in two of the studies. Kerr *et al.* (1999) note that warmer sunnier weather would have a positive 'feel good' impact on the population, whilst Russell (2000) identified negative mental health effects of extreme weather events. Analysis of the 1953 Bristol floods showed that temporary displacement or loss of one's home through flooding or storm damage can be extremely traumatic for affected individuals, and may call for counselling at the expense of public health services.

3.4.4 Recommendations from UKCIP scoping studies

Many climate impacts on health are avoidable if necessary steps are taken in time. Several recommendations for minimising future impacts were raised in the studies.

A call was made for further research into the issue. Better certainty in climate change and health impacts assessments was considered essential for informing responses to climate change impacts. Wade *et al.* (1999) argued that such analyses should be conducted at a national, and not a regional, level.

All studies presented a strong argument for adopting an interdisciplinary approach to assessing impacts, developing responses and reducing vulnerability of human health to climate change. Understanding the links between housing, energy use, climate and health need to be improved if meaningful responses are to be developed, particularly in Scotland where health will be integral to a host of issues including water quality, housing quality, and provision of health care services. Impacts in South West England will be influenced strongly by changes in exposure to risk owing to altered lifestyles, and access to health care services. It is only through the integration of expertise in related disciplines that such understanding can be achieved.

The Wales, South East and South West England assessments emphasised the importance of increasing public awareness of potential health impacts, as many risks can be avoided with simple behavioural changes. For example, education in food hygiene and awareness of how to minimise exposure to heat stress, UV and communicable diseases or pollutants could significantly reduce the incidence of food poisoning and vulnerability to disease.

Farrar *et al.* (2000) make several recommendations for enhancing preparedness of the UK as a whole for changes in health risk:

- Environmental risk managers should be trained to recognise and cope with health impacts likely to arise from climate change;
- Better monitoring of health risks is needed to control potential outbreaks;
- Plans for coping with emergencies (outbreaks of food poisoning, epidemics, floods) should be developed; and

- Protocols are needed for the treatment of communicable diseases.

Since implementing such actions will be governed by economic constraints, central guidance in developing a health response will be critical.

Findings from the UKCIP scoping studies highlight the importance of the DH Expert Review. It is hoped the report will provide much needed analyses and will outline what further research is required to improve our understanding of this important issue.

3.4.5 References

CCIRG. (1996). *Review of the Potential Effects of Climate Change on the United Kingdom*. HMSO, London.

Farrar, J., Vaze, P., Hulme, M. and Reynolds, B. (2000). *Changing Climate Challenging Choices: The impacts of climate change in Wales from now to 2080 – Technical Report*. Report prepared for the National Assembly of Wales. In press.

Hulme, M. and Jenkins, G. (1998). *Climate Change Scenarios for the United Kingdom - Summary Report*. UKCIP Report No.1. Climatic Research Unit, Norwich. 16pp.

Kerr, A., Shackley, S., Milne, R. and Allen, S. (1999). *Climate Change: Scottish*

Implications Scoping Study. HMSO, Edinburgh. 75pp.

Kovats, S. and Bentham, G. (1999). *Report on the Health and Demography Workshop at the Climatic Challenge Conference*, St. Mellion, Cornwall, 28th –29th October 1999.

McMichael, A.J. (1996). Human population health. In R.T. Watson, M.C. Zinyowera, R.H. Moss and D. Dokken, (Eds.) *Climate Change 1995. Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses*. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge: Cambridge University Press.

Russell, K. 2000. The Climatic Challenge Conference, Delegate Information. 28th –29th October, 1999.

Shackley, S., Wood, R., Hornung, M., Hulme, M., Handley, J., Darier, E. and Walsh, M. (1998.) *Changing by Degrees - The Impacts of Climate Change in the North West of England: Technical Overview*. University of Manchester, Manchester. 63pp.

Wade, S., Hossell, J. and Hough, M. (Eds.) (1999.) *The Impacts of Climate Change in the South East: Technical Report*, WS Atkins, Epsom, 100pp.

3.5 Review of external projects using the UKCIP98 climate scenarios

3.5.1 Background

In addition to the use of the climate scenarios within UKCIP studies, other projects can become licensed to use the data for their research. The information is distributed on a CD-ROM, which contains baseline (1961-1990) climatological data for the UK and Ireland, as well as data for the four UKCIP98 climate scenarios (low, medium-low, medium-high, high) for the 2020s, 2050s, and 2080s. Also included are GCM model runs providing a simulated output of natural variability (without the anthropogenic greenhouse gas forcing) for reference. The data are available either in the original GCM grid boxes (ca. 250km) or as values down-scaled to a 10km grid. Monthly, seasonal or annual values can be queried. Access to the data is facilitated through a menu-based user interface, which allows tables and maps to be produced. In addition, the data can be exported to a geographical information system (GIS) for more specialised processing, if required.

Distribution of the CD-ROM began in March 1999, so detailed conclusions on the use of the data can not yet be drawn. Most of the projects have been in operation for less than a year, and results and publications have therefore not yet been completed. However, some projects which represent a continuum from previous studies pre-dating UKCIP, and for which a methodology had already been established, have results which can be reported here. For the remainder of the ongoing projects some general conclusions can be drawn. One source of encouragement is the varied range of users that have been licensed to use the data, derived from several different sectors. These sectors are discussed in turn, to evaluate the scope and direction of research. Most of the results that can be reported at this stage, are from the water resources sector.

3.5.2 Water resources

Previous work by Arnell (1997) on the potential hydrological impacts of climate change has continued, with a study

commissioned by the Environment Agency to evaluate water resource assessments based on the UKCIP scenarios (Arnell, 1999a,b). The first phase of this work involved calculation of regional flow factors for 2020 based on the four UKCIP scenarios, as an update to previous work using the HadCM2 model input (Arnell, 1997). For the first phase study, a daily streamflow model is applied to 61 catchments and 9 aquifer units in the UK. Under all UKCIP98 scenarios, increased flow is ubiquitous in winter, whilst in summer reduced flows occur in southern England. Groundwater recharge increased under all scenarios. Low flow levels were reduced across all regions except for Scotland and Northern Ireland and also some groundwater-fed catchments.

The second phase of the work involved looking at long-term natural variability to assess the following:

- implications of natural multi-decadal scale variability in addition to the anthropogenic atmospheric loading;
- implications of year-to-year variability.

Attention was focused on 16 of the original study catchments using a general hydrological model. Comprehensive use of the UKCIP climate data was made, comparing stream-flow generated by the natural variability data against that produced by variability between the four ensemble results for the medium-low and medium-high scenarios. The results generally imply that, for average flow conditions, the magnitude of variation from one 30-year period to another was greater for natural variability than for climate change before the 2020s. No clear pattern emerged for natural variability in time and space however. Natural variability will therefore have a significant effect on 30 year mean flows in

addition to impacts from climate change. This natural variability needs to be built into estimates of hydrological resources, notably for catchments with less than 40 years of hydrological data.

The implications of year-to-year variability are important because the climate scenarios suggest this relative variability may increase in the future. Model runs showed that altering both variability and the mean had relatively little effect on average annual or monthly runoff but had a substantially greater effect on the frequency of low flow threshold values, which were implied to be 5-10% less. Lower groundwater recharge may also occur, although this is uncertain because model results for a minority of aquifers showed increased recharge. These results suggest that incorporating year-to-year variability into impact predictions leads to different, usually more extreme, low flows levels (and by inference, high flows also). Future work is planned to extend these assessments into the 2050s and 2080s. Work on natural variability had previously been hindered before the availability of the UKCIP CD-ROM, as there were no credible sources for changes in relative variability.

The work of Arnell used a hydrological model applied to chosen case study catchments, and the results cannot be directly transferred to other non-study catchments because of their differing responses. A more empirical modelling approach has been developed by Severn Trent Water, using the UKCIP98 scenarios, for modelling water yield in specific catchments (Kitson, 1999). The data have been used to quantify future changes in catchment hydrology up to 2050 by determining the trend using the baseline, 2020 and 2050 time-slices for all four UKCIP98 scenarios. GCM and baseline data are fed into a catchment model, together with physical and geological data. These in turn drive a resource system model with environmental and distribution system constraints (e.g. licenses, pipeline and treatment capacity) to determine deployable output. In the Wye catchment, models have been developed to analyse the increased risk of flooding due to spills from the Elan Reservoirs, and also to estimate reduced yield from these reservoirs. For the Severn, assessments have been made of the

number of flood days on the lower river (at Bewdley) and the deployable output from the catchment. Similarly, deployable output has also been estimated for the Derwent in the East Midlands. In all cases, deployable output is found to be reduced by varying degrees, depending on the climate scenario.

Related work on groundwater recharge provides a more optimistic assessment of the impact of climate change. Here, the climate data are combined with aquifer characteristics in a groundwater and distributed recharge model to determine the available head. Each of the scenarios suggests that a varying degree of improved cumulative recharge of the Nottinghamshire Triassic Aquifer will occur due to the increased winter rainfall. These data can then be used to calculate the accumulated baseflow to the River Maun.

This work shows the importance of detailed modelling on individual resource units using the common GCM outputs provided by the UKCIP scenarios. However, there is a suggested need for more explicit confidence limits in the scenarios, as this has major implications for the scale of changes that are predicted. As part of the next stage of their work Severn Trent also plan to link hydrological changes and water quality to potential impacts on aquatic ecology.

Thames Water are also applying the scenarios in their evaluation of the long-term impacts of climate change on domestic water demand (Downing, *pers. comm.*). A new model (*TWDemand*) of the relevant relationships has been developed. The key features include a dynamic approach that models micro-component ownership, use and flow on a monthly time-scale with sensitivity to climatic variations. This approach provides a cross-check to the empirical, econometric approach widely used in the industry. It is more robust for understanding future conditions and consumer behaviour than deriving statistics from past relationships.

The *TWDemand* model uses the four core UKCIP scenarios, and also the most extreme ensemble member (number 3) from the medium-high scenario, to illustrate how an individual run can differ from the mean.

However, this ensemble member does not translate into significantly different impacts. The monthly GCM values are averaged over three months to smooth out the changes from month-to-month. From 1998 to 2080, climate data are generated for each scenario, based on a random sample with the scenario mean and historical standard deviation (the seed number is specified so each sequence can be repeated). An option to include scenarios of climatic variability uses projected changes in the standard deviation to alter the random time series with different (in most cases greater) variance.

The model is seeking to frame climate change impacts as a risk assessment. Model results were interpreted as a distribution of risk, based on subjective probabilities of the range of changes (including climate change). However, the model does not involve any statistical downscaling and assumes variability is a simple random process. Further work is therefore proposed, particularly on persistent drought episodes.

Similarly, the UKCIP98 scenario data have been used in a scoping study carried out by WRc on behalf of UKWIR, to investigate seasonal droughts and the priorities for future research. One of the observations of the study was that no detailed resource assessment similar to the EA/UKWIR study (Arnell, 1997) has yet been carried out using the more robust UKCIP scenarios. It was also suggested that there is a need for a risk and uncertainty approach to be developed for further research.

Further hydrological use of the scenarios data has been made in a project based at Herriot-Watt University, which is assessing the degree of uncertainty inherent in predicting climate change impacts on water resources. As both baseline and future hydro-climate data are input into simulation models of catchment response, errors can be propagated through the modelling process. By incorporating stochastic modelling techniques (Monte Carlo simulation is used in this study), the level of uncertainty can be quantified. This has important implications for determining the true yield and resilience of reservoirs. Preliminary results have so far been presented for Yorkshire up to 2020 (Adeloye, Nawaz and Montaseri, 1999).

Work is also in its early stages at the University of Portsmouth using the scenario data for a project examining the impact of climate change on the geomorphology of river channels.

3.5.3 Ecology and biodiversity

Extensive use of the UKCIP scenario data has been made by Quest Environmental in their consultancy work at certain sites. With regard to a proposed new reserve on the Great Ouse at Needingsworth, medium-high scenario data for 2020, 2050 and 2080 were applied to a simulation model that had been developed to estimate water demand for reedbeds. This allowed an assessment of the potential impact upon the concentration and mass fluxes of key nutrients within the proposed reserve. The climate data enabled possible changes to design and operations to be planned in advance and the RSPB could present long term scenarios to the Environment Agency for planning consent for the reserve.

Another area in which Quest Environmental have been involved, and the UKCIP scenarios utilised, is Loe Pool SSSI (Cornwall) where The National Trust are undertaking a review of Environment Agency plans. The plans have been criticised because they do not directly address models of climate change or the local impact of sea level rise. Hence, the National Trust has commissioned a simulation model of the basin hydrology and its chemical balance. Similarly, UKCIP data are being used in a review of restoration options on the adjacent River Cober, to understand the full geomorphological and hydrological implications of remedial work on the extensive channelisation of the river in the 1980s.

CABI Bioscience are using the scenarios to examine the effects of climate change on calcareous grasslands, extending their previous work on these nationally important and sensitive areas, which contain a high degree of biological diversity (Sternberg *et al.*, 2000; Thompson *et al.*, 2000). The scenarios are being used as a reference level for change against which the response of the plant and invertebrate community to ecological change

is analysed. Detailed field studies, in which the microclimate has been manipulated, are combined with integrated vegetation models to provide the necessary experimental validation.

Another project where the scenarios data are being used, aims to ascertain the impact of future climate at a site near Annan, south west Scotland, where intertidal peats and fossil oaks in eroding cliffs have been declared of national importance by the Geological Conservation Review. The information is being used by the Centre for Field Archaeology, University of Edinburgh to advise Scottish Natural Heritage on management options at the site.

With regard to bird populations, the British Trust for Ornithology (BTO) is using the data to study the impact of climate change on the distributions of waders (e.g. ringed plover, redshank). Although found mainly on the east coast of Britain, during continuously cold winter weather, the birds will temporarily migrate to the west coast. The BTO study involves relating bird distributions to the present weather pattern using observational records, and then assessing the future impacts on waders from scenario data. This may explain the declining population of waders in Wales, and has major implications for the future location of protected sites (Rehfishch and Austin, 1999).

JY Lee (Napier University) is using the data in a coupled physical-biological model of marine ecosystems. This work is examining the changes in nutrient loading from increased rainfall and increased stratification in estuaries (such as the Firth of Forth) that lead to hypoxia.

3.5.4 Agriculture and forestry

Several MAFF-funded projects are now using the UKCIP scenarios to evaluate impacts on the agricultural sector. One of these projects is on the timescale of potential farm-level responses and adaptations to climate change. This could greatly affect farm enterprise and profitability, therefore a wide range of different farm types scattered in different agricultural zones across England and Wales has been investigated for sensitivity. Farm-

level enterprise models are combined with models predicting yield and soil moisture balance, together with data from the UKCIP medium-low and medium-high 2050 scenarios. The results are compared with a baseline model run (with and without the Agenda 2000 reforms). The most sensitive area and farm types will also be incorporated in assessments for 2020.

The Farm and Rural Conservancy Agency (FRCA) are using the scenarios to identify possible implications of climate change on the Agricultural Land Classification System which maps land use (Grade 1 to Grade 5) based on climate, topography and local physical conditions. The future climate data will be used to produce a new classification map indicating the best and most versatile land for agriculture.

With regard to crops, Horticultural Research International (HRI) have used the scenario values for local sites to model the effects on flowering, maturity and yield for the French bean. The scenarios provide the range of temperatures that are combined with concurrent future carbon dioxide concentrations to derive the response models (Wurr, submitted).

Similarly, the range of scenarios was used in a project investigating the influence of climate change on invasive insect pests in the UK. The interactions of the western flower thrips (*Frankliniella occidentalis*) and several aphid species to both elevated temperature and carbon dioxide are being examined. Stacey (1999) has presented a general review of the effect of warmer winters on insect pests. It is possible that if an insect pest invades a new area, then its associated enemies may not follow because the extended range is not suitable for them. Warmer winters tend to favour survival of pests but wetter winters would act against them, hence the 10km scale of the UKCIP climate data can be used to model their possible distribution.

Forest Research have been using the CD-ROM data in the ECOCRAFT project which provides predicted impacts of rising carbon dioxide and temperature on forests in Europe at stand scale. Model simulations have been produced for the UK, which simulate the

volume of Sitka spruce and oak for future time slices up to 2080. Modelling work is also continuing on other aspects of climate change on forest growth, particularly the effects of drought in southern England.

3.5.5 Coastal zone

The UKCIP climatological data have been utilised in two projects investigating the changing wave climate around the British coast. A MAFF-funded project undertaken by HR Wallingford (Brampton and Harfor, 1999) has been examining the implications of waves on UK coastal/flood defence. It found a close correlation between present-day mean-monthly wind speed and wave height, suggesting that modelled wind outputs from GCMs may be suitable for wave height prediction for the future. However, the project ideally requires more detailed GCM data than is available at present, especially on wind velocities, with 'wind roses' summarising the probability of different wind speed and direction combinations.

The other study examining the wave regime is the JERICHO project (Cotton *et al.*, 1999). The participants in this project are: Satellite Observing Systems; Southampton Oceanography Centre; Proudman Oceanographic Laboratory; and Sir William Halcrow and Partners.

The objective of JERICHO has been to investigate how satellite data, in-situ ocean instruments and shallow-water wave models can be combined to investigate which parts of Britain's coastline may have experienced an increase in wave height similar to that observed in the surrounding seas by satellites (an increase in winter of about 10% over the last decade). Satellites cannot measure right up to the shoreline, however, because the offshore signal to the sensor becomes contaminated by land within the footprint. Previous research has used output from the HadCM2 GCM in the wave model and it is intended to update this with the UKCIP data. However, the lack of specific data on "storminess", has meant that current work has used arbitrary worst-case scenarios of offshore wave height combined with data on sea level rise. This has shown that

changing wave height may be as significant a component for sea defences as rising sea level.

With regard to sea-level changes, Scottish Natural Heritage has funded a study to assess the potential impacts of climate change on sea levels in Scotland (Dawson *et al.*, in press). This has used geological and tide gauge data in conjunction with the scenarios data to produce maps of sea-level rise around the coast and storm surge probabilities (1:50 and 1:100 year return periods). The scenarios have been used to work out the range of impacts by using worst-case and best-case scenarios along with a "best estimate" scenario for both 2050 and 2100. A series of maps illustrates spatial variations in the susceptibility of the Scottish coastline to future marine flooding.

3.5.6 Buildings and structures

The scenario data are being used in several studies in this sector, but these are still in the early stages. For instance, Buckinghamshire College is using the data to examine the potential spread of the house longhorn beetle (*Hylotrupes bajulus*) which infests wood; the study is using flight threshold data to examine the mobility of this insect pest. The UKCIP data are also being used by HM Nuclear Installations Inspectorate to ensure their licensees are incorporating the data in safety tests, building on previous work using climate change models. The scenarios were also used as a reference level in a Met. Office study aiming to increase the awareness of storm and wind damage within the UK insurance industry. A study is also being undertaken by the Building Research Establishment (BRE). The UKCIP medium-high scenario data are being used to undertake technical assessments of the potential impacts of climate change on building structures, materials performance, energy use in buildings and the construction process.

3.5.7 Other studies

In a number of cases, the UKCIP98 scenarios are being used to provide local information on climate change, rather than as inputs to detailed modelling. The data therefore promotes increasing awareness of the

predicted magnitude of local change against the baseline. Hence, local authorities, such as Glasgow City Council, are using it to assist in the planning process (particularly with regard to flooding). Similarly the Broads Society are using the CD together with the UKCIP Technical Report (Hulme and Jenkins, 1998) to promote local awareness on climate change and to encourage further research on a vulnerable area. The data are also being used to assist in the development of the Environmental Change Network and Climate Change Indicators (co-ordinated by the Institute of Terrestrial Ecology). Finally, although not the original intention of the CD, some projects have currently used only the 1961-90 baseline data, which in itself provides a readily accessible and rich source of data on the mean spatial variations in the current climate. This can assist in identifying the present susceptibility of sectors to climate, and encourage further research on potential future susceptibilities. In this context, future plans for a 5km scale climatology (rather than 10km at present) will no doubt be very welcome.

3.5.8 Evaluation of use of the UKCIP98 scenarios data

Useful feedback has been obtained from the users of the CD-ROM on the presentation of the data, the quality of the user interface, and the range of data available. As may be expected, several users requested more specific data in future scenarios. Further data on wind speeds and storminess was a common request (e.g. minimum and maximum wind speed), in line with comments solicited from internal UKCIP studies that it would be desirable to have more information on extreme events. It was also suggested that a breakdown of the GCM output between convective and frontal rainfall would be useful for some studies. Other useful climatological variables identified are high-level cloud cover, net radiation, sea surface pressure, snow cover, North Atlantic Oscillation values and surface albedo. The need for more specific data for agricultural and vegetation research was also identified (e.g. crop moisture deficits, field capacity days, accumulated temperature above 0°C, soil moisture, evapo-transpiration related to vegetation and soil characteristics) and the

need for daily rather than monthly values. It was also a common request that all time-slices (baseline and scenario) have the same data variables throughout, such as rainfall intensity. Clearly, not all these requests may be met, and others may be better handled by more sectoral organisations, but the feedback shows where the current gaps in data are perceived to be.

Considering the time-span for which the CD-ROM has been available, it is too early in the process to ascertain in detail how the scenarios have been used. At present, only one user (Arnell) appears to have used the full range of data (i.e. all 4 scenarios, with the individual ensembles for the medium-low and medium-high scenarios, together with the natural variability data). Some of the other users have used the four scenarios (with the ensemble means) but the natural variability data remains under-utilised. However, more typically researchers use either one or two scenarios. Hence, some studies have used the low and high scenario to determine the 'full range' of impacts, whereas others have used the medium-high or medium-low as modal estimates.

Dialogue with users of the CD-ROM is an on-going process, and it is hoped that a more complete review of the use of the scenarios may be made in a year's time. Information on the projects is also added to the research inventory being compiled by UKCIP, and this should facilitate better integration between projects. The feedback obtained can also be used to improve dissemination of information from the next generation of UKCIP scenarios. For example, an option to be considered for the future is to allow licensed users to access the data across the Internet, as this would ease considerably the distribution and updating of data-sets.

3.5.9 References

Adeloye, A.J., Nawaz, N.R. and Montaseri, M. (1999). *Assessing the impacts of climate change water resources impacts using a Monte-Carlo simulation approach*. Proceedings of the 2nd Inter-Regional Conference on Environment-Water 99.

- Arnell, N.W., Reynard, N.S. King, R., Prudhomme, C. and Branson, J. (1997). *Effects of Climate Change on River Flows and Groundwater Recharge*. UKWIR/Environment Agency. Report 97/CL/04/1.
- Arnell, N.W. (1999a). *Effects of climate change on river flows and groundwater recharge: update with the 1998 UKCIP scenarios*. Report to Environment Agency. Department of Geography, University of Southampton.
- Arnell, N.W. (1999b). *Effects of global warming on water resources: implications of multi-decadal variability and changes in year-to-year variability*. Report to Environment Agency. Department of Geography, University of Southampton.
- BBSRC (1997). *Proceedings of the Biological Adaptations to Global Environmental Change (BAGEC) Programme*.
- Brampton, A. H. and Harfor, C.M. (1999). *Wave climate change. Indications from simple GCM outputs*. HR Wallingford Report No. TR 80.
- Cotton, P.D., Carter, D.J.T., Allan, T.D., Challenor, P.G., Woolf, D., Wolf, J., Hargreaves, J.C., Flather, R.A., Bin, L., Holden, N. and Palmer, D. (1999). *JERICHO: Joint Evaluation of Remote Sensing Information for Coastal and Harbour Organisations*. Final Report to the British National Space Centre.
- Dawson, A. G., Smith, D.E. and Dawson, S. (2000). *Potential impacts of climate change on sea levels in Scotland*. Report for Scottish Natural Heritage. In press.
- Hulme, M. and Jenkins, G. (1998). *Climate Change Scenarios for the United Kingdom*. UKCIP Technical Report No. 1. University of East Anglia, Norwich. 80pp.
- Kitson, T. (1999). *The truth about water resources - a traverse from the wet west to the dry east*. Paper presented at the Climate Change Conference, ICC Birmingham. 26th May 1999.
- Rehfishch, M. and Austin, G. (1999). Ringed Plovers go east. *BTO News*, **223**, 14-15.
- Stacey, D.A. (1999). Insect responses to warmer winters in the UK. *Aspects of Applied Biology*, **53**, 137-142.
- Sternberg, M., Brown, V.K., Masters, G.J. and Clarke, I.P. (2000). Calcareous grassland vegetation responses to the field manipulation of local climate. *Plant Ecology*, **143**, 29-37.
- Thompson, K., Masters, G.J., Grime, J.P., Brown, V.K., Clarke, I.P., Hillier, S.H., Askew, A.P., Corker, D. and Kielty, J.P. (2000). Predicting the response of limestone grassland to climate change. *Aspects of Applied Biology*, **58**, In press.
- Wurr, D. Climate change: a response surface study of the effects of CO₂ and temperature on the growth of French beans. Submitted to *Journal of Agricultural Science*.

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Chapter 4

Discussion and Integration of Main Results

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- 4.1 Results from impacts assessments in Scotland, Wales, North West England, South East England and South West England**
- 4.2 Cross-cutting issues**
- 4.3 Summary and synthesis of conclusions from studies**
- 4.4 References**

This Chapter presents the main results from the UKCIP studies and integrates them in a qualitative way. The Chapter is structured in the following way: Section 4.1 examines the main findings of the scoping studies in Scotland, Wales and the regions of England. Section 4.2 examines cross-cutting issues relating to the studies, including the use of methodologies and so also draws upon experience with the sectoral reviews underway. Section 4.3 provides an integrated summary of conclusions from the impacts assessments, and outlines issues for adaptation and recommendations for further research.

4.1 Results from impacts assessments in Scotland, Wales, North West England, South East England and South West England

Key findings from the sub-UK scoping studies are presented in Section 4.1 in the following order: water resources and quality; flooding and coasts; the changing countryside; business impacts and health. The key findings are summarised in Table 4.1a.

4.1.1 Water resources and quality

Headline impacts issues in studies:

- Meeting summer demand with reduced and more variable precipitation, and coping with heavier winter rainfall
- Waste water treatment
- Reduced water quality in rivers (e.g. chalk streams in South East England)
- Providing industrial supply, especially to SMEs dependent on water (e.g. breweries, paper mills)

A major issue to emerge from all scoping studies was concern over meeting increased summer water demand with reduced and more variable precipitation, or coping with the implications of heavier winter rainfall. The

problems assumed different dimensions in each part of the UK.

Meeting water demand, particularly in summer, will be a growing challenge in South East England where average household consumption rates are already higher than the national average and further growth is expected. Of particular concern to South East England is the impact of 'back to back' droughts and possible over-abstraction of aquifers. Further assessment of these issues is required as the next step in informing water resource planning.

Contrasting challenges emerge in Scotland where generally plentiful water resources are likely to increase. Given that water storage facilities are typically at capacity at the start of winter, higher runoff and excess surface water are likely to become more problematic. This has implications for water quality and waste water storage and treatment. If the intensity of rainfall events changes substantially, the sewage infrastructure will require upgrading to comply with European Community Directives on waste water quality. Water colouration from peat-rich soils may increase in Scotland and North West England, with implications for water treatment.

With nearly 60% of water abstracted in Wales currently exported to England, and demand for Welsh water likely to increase in both Wales and England, there could be sensitive issues to resolve. There is concern that greater demand for water under a changed climate could have knock-on effects for water quality in Wales, should more water be sought from there, and that Wales may experience difficulty in providing an adequate water supply during dry summers by the year 2025.

Concerns in Wales are borne out by findings of the North West England study. This region is currently fairly resilient to changes in water resources owing to its highly integrated water supply system, which includes major aqueducts and transfer links that bring water from reservoirs and lakes in North Wales to Merseyside and from Cumbria to Greater Manchester. Should climate change increase the severity and frequency of droughts in Wales and North West England, meeting demand will become a significant challenge.

Table 4.1a: Main results from scoping studies in Scotland, Wales, North West England, South East England and South West England.

Key impacts

- Meeting demand for water in summer and coping with excess surface waters in winter.
- Politics of water supply / distribution set to become a major issue.
- Reduced water quality owing to: colouration in peat-rich areas; flushing of pollutants in heavy rains following droughts; soil erosion; run off.
- Increased risk of coastal and estuarine flooding with implications for coastal infrastructures and habitats around the UK. Similarly river floodplains face an increased level of risk.
- Fisheries in South West England and Scotland.
- The nature of the countryside is likely to change both through changes to natural habitats and changes in agriculture and land use.
- Businesses dependent on water resources are most vulnerable to climate change.
- Health impacts mixed. Further work needed at national scale to improve understanding.

Cross-cutting issues

- Integrated assessment is essential for fuller understanding of climate change impacts, particularly in relation to water resources and quality, and human health.
- Stakeholder interviews are an effective route towards obtaining information not yet reported in the literature, but suffer several limitations.
- Climate change scenarios and analogies to past extreme events are powerful communication tools in getting people to think about climate change impacts.
- Extreme weather events are a useful ‘hook’ to engage people in conceptualising climate change.
- Greater public awareness of climate change and its impacts is needed to develop appropriate responses.
- Some institutions will struggle to adapt to climate change owing to institutional inertia, conflicting priorities, lack of certainty in the climate predictions and disparity between planning and climate change time-scales.

Summary of issues for adaptation

- Policy environment needs to facilitate integrated planning and decision-making.
- Responsibility for riverine and coastal flooding management needs to be further clarified.
- ‘Climate change headroom’ is needed for planning new facilities and infrastructures. Climate change should be integrated into building regulations and water resource management.
- Flood defence is a major issue in all regions.
- Additional resources are needed to speed up programmes of physical infrastructure.
- Actions on adaptation will depend on decision-makers being convinced they have sufficient information to act, either by having more information on impacts or better guidance as to how to handle the uncertainties in climate change.
- Leadership is required to mobilise action (to overcome institutional inertia) and provide guidance and information.

Research recommendations

- Regional climate change scenarios, particularly for Scotland and Wales.
- Further information on extreme events, specifically gales, coastal storm surges, back-to-back droughts, rainfall intensity, extreme temperature events.
- Data of a higher temporal resolution.
- Fuller socio-economic models.
- Better baseline data with which to develop necessary tools for assessment.
- Regional climate change indicators to monitor the impacts of climate change.
- Investigating the relationship between tourism and weather.
- Integrated health assessment.
- Greater certainty in climate change scenarios.

It is clear from all studies that planning based on average conditions is not adequate to plan for future water resource management. Further attention should be given to the intensity and duration of droughts, which will be the critical determinant in meeting future water demand. Rates of change and the possibility of extreme events will also require consideration. Indeed, water resource management in all regions will have to consider the additional risks that climate change adds to the assessment of sustainable resource availability and forecasts of future demands.

A finding common to all studies is that the effects of climate change on precipitation patterns, demand management measures, agricultural and urban run-off and increased temperatures will influence water quality. Impacts of changes in each variable have been assessed, but the collective impacts of these changes have yet to be considered in an integrated manner. This issue was highlighted in the North West England and South East England studies, the latter concluding that the combined impacts on water resources may result in a serious deterioration in water quality, with consequent changes in the biological quality of some of the region's valued chalk streams. An integrated approach to water resource issues is required if water quality standards are to be maintained.

4.1.2 Flooding and coasts

Headline impacts issues in studies:

- Increased flood risk in coastal areas, estuaries and river floodplains affecting housing, industry, transport and other infrastructure and utilities, as well as the natural environment
- Impacts of sea level rise, increased storminess and altered wave energy on important ports
- Disruption to railway lines and coastal industry
- Potential impacts on fisheries (e.g. declines in migratory salmon)
- Potential impacts on the rate of coastal erosion in some areas

Since the removal of ice after the last glacial maximum, the land of the UK has responded by gradually rising in northern Britain and

subsiding in southern Britain. Concurrently, global sea level has risen and the present rates of sea level rise are projected to accelerate due to climate change. Parts of the coastline are thus particularly vulnerable to coastal flooding because subsidence will increase the change in sea level.

The effects of rising sea levels, increased storminess and altered wave energy were identified as a major concern to a host of interests around the UK. The coast of South East England, for instance, is highly developed, with near-continuous sea defences around 1200km of coast. Older coastal protection schemes did not factor-in climate change and the costs of maintaining or upgrading these schemes may be too great to justify.

Concerns about increases in coastal flooding were key issues in all studies. Specific areas identified within the regional reports as being particularly prone to flooding include coastal estuaries and low-lying coastal land. Many cities and major facilities (e.g. energy and chemical plants) are sited in coastal locations, such as along the Cumbrian coast and Mersey, Ribble and Lune estuaries in North West England. Other vulnerable estuaries were identified as the Dee, Dyfi and Severn in Wales, and the Arun in South East England. It is thought that the effects of sea level rise are likely to be more localised in Scotland than elsewhere in the UK given its steep-sided coastal topography.

Much low-lying coastal land has critical importance economically, for human habitation, for tourism, or for its natural habitats. Predictions under climate change of an increase in the frequency of those conditions currently producing coastal or inland flooding are causing concern. On a national level, many vulnerable areas exist, but threatened areas identified in the scoping studies include the Gwent Levels, Denge Peninsula, north Kent coastline, Isle of Sheppey, Somerset Levels and the Isles of Scilly. In addition, steep-sided valleys in South West England (e.g. Polperro, Pentewan) are particularly vulnerable to flash floods, and in Wales many rivers are notorious for major flood events (e.g. Wye, Usk, Conwy).

Impacts of sea level rise, together with potential increases in storminess and altered wave energy are expected to be particularly important for some of the larger ports, such as Heysham Harbour in North West England and Dover in South East England. They also have implications for shipping operations between the Scotland mainland and island communities. Existing infrastructure for shipping and ferry operations in Scotland are robust against current forces of wind and tide, but alterations to existing ports, piers and ferries, and new designs, will have to take climate change into consideration. Improved information on storm frequency is therefore vital. Coastal transport infrastructure around the UK, such as the railway line around Dawlish in South West England and along the west Cumbrian coast are also vulnerable to sea level rise.

Fisheries in South West England and Scotland were identified as being vulnerable to changing ocean temperatures. Evidence suggests that recent declines in both migratory salmon and some marine species may be linked to fundamental changes in ocean circulation around Scotland, whilst anecdotal evidence suggests warm-water species are being observed more frequently off the Cornish coast. Changes in the productivity or variety of catches would significantly influence this important economic activity in these regions.

4.1.3 The changing countryside

Headline impacts issues in studies:

- Loss/reduction of rare or important species
- Benefits to some species
- Habitats – drying of heathland, changes to uplands and wetlands
- Coastal squeeze resulting in loss of mudflats and salt marsh
- Changes in agriculture – new crops
- Summer drought and heavy winter rains pose difficulties for farmers
- Forestry expected to benefit but increased risk of fires and pest damage

Climate change is likely to have a profound impact on the countryside across the UK. Wales and South West England, with their high quality rural landscapes and a high proportion of coasts and land designated for

environmental protection, are considered to be particularly vulnerable to climate change impacts. Scotland considers its natural environmental resources to be the single sector most likely to be affected by climate impacts.

In Wales, there is concern over the future of particular species such as the Snowdon Lily and the dipper, whilst numbers of the kingfisher and nightingale are likely to increase under climate change. In the uplands, arctic-alpine species are likely to suffer in Scotland (e.g. snow bunting) and Wales as their preferred habitats warm. Species in South East England that may benefit include the Adonis blue butterfly, some lowland grassland orchids, and rare reptiles in heathlands. However, those species that prefer wetter heathlands (e.g. the mole cricket and marsh gentian) may suffer as their habitats dry out. In North West England, the Speckled Wood and Comma butterflies, Black Bryony and Horseshoe Vetch may extend their range northwards, and populations of butterflies and dragonflies in Morecambe Bay may increase. Remnants of ancient plant and animal communities in the Cumbrian fells and lakes are at risk from habitat change, including species such as the Mountain Avens, Alpine Lady's Mantle, and rare saxifrages.

Coastal squeeze could result in the loss of mudflats and salt marshes, which often act as the first line of defence. Specific areas have been noted in South East England (e.g. the North Kent coastline), North West England (the Solway Firth, Morecambe Bay, Ribble, Mersey and Dee estuaries) and Wales (Mawddach estuary). Some internationally significant bird feeding grounds may be reduced in size as sea level rises, unless managed realignment is undertaken. The need for climate change to be factored into criteria for site designation is seen as an important step towards protecting, or managing, vulnerable landscapes in a changing climate.

Some of the UK's most distinctive landscapes are likely to be affected by the changing climate including the Hampshire Downs, South Downs and New Forest in South East England, the uplands of Wales, the Lake District, the Cairngorms and more generally, estuaries and wetlands.

Changes in agriculture will also have a profound impact on the landscape. Across the south of England (e.g. Hampshire, West and East Sussex, Cornwall and Devon) new crops may become viable, such as soya bean, sunflower and grapevines. However, opportunities for more widespread crop production earlier in the season could result in South West England losing its current competitive advantage over other regions of the UK for certain products. Warmer conditions may see arable agriculture increasing in eastern Wales but it is thought that projected climatic changes in Scotland are not sufficiently large to act as a major driving force of agricultural change.

Summer drought will pose a major problem to farmers in the south of the UK where water shortages could affect crop production. Increased frequency of droughts would also result in more frequent desiccation of clay-rich soils, and an increased possibility of rapid pollutant transfer to watercourses when heavy rains fall. Horticulture in North West England will be similarly affected by water supply problems, particularly near Preston and Ormskirk. However, the main threat to farmers in North West England and Scotland arises from higher winter rainfall which is likely to present considerable operational difficulties with waste water management systems, and the use of machinery on waterlogged land.

Throughout the UK, climate change could increase the risk of soil erosion. An extended season of outdoor grazing would increase erosion in all regions. Hot, dry summers in South East England could increase the risk of wind erosion, whilst in North West England, upland soils and the sandy and peat soils of the Fylde plain would be vulnerable.

Forestry is one activity likely to benefit from climate change throughout the UK. Scoping studies implied that elevated temperatures and carbon dioxide concentrations will increase growth rates and yields, but increased damage from wind, fire and pests or diseases are causes for concern in all regions.

4.1.4 Business impacts

In general, stakeholders consulted in the business community attached a low level of

Headline impacts issues in studies:

- Generally low awareness of possible impacts
- Industries reliant on water could suffer
- Opportunities for growth in tourism and leisure
- Insurance – more weather-related claims

importance to climate change issues. This was attributed to a combination of their short-term planning horizons (particularly amongst SMEs), the perceived unimportance of climate factors relative to social or economic change, a limited appreciation of the effects that climate change will have on business, and a perceived ability to adapt to changing conditions. Furthermore, some businesses were more concerned about the impact of forthcoming climate mitigation measures than they were about climate change impacts. A further explanation for this finding was that the economy of the UK is dominated by the service industry, which appears to be less sensitive than other business operations to the direct impacts of climate change.

A finding common to most of the scoping studies was that the insurance industry had high awareness of, or preparedness for, climate change. More weather-related insurance claims could affect the performance of the insurers, although yearly adjustments allow rapid response to changed profitability. In addition, the Scotland scoping study stated that its financial sector could be affected by the impacts of climate change on investments and insurance claims in other parts of the world. It was considered likely that other trends in the insurance industry will also influence this sector, increasing the significance of climate change. For example, if the move towards more individual accountability observed in car insurance extends to house insurance, it may increase the significance of flood and storm damage risk. This may provide an incentive for more rational planning decisions in the future with respect to development in higher risk areas, but equity issues will certainly arise with respect to the owners of existing property. SMEs based in South East England that are reliant on water supplies, and chemical plants in coastal locations of North West England, were also aware of their vulnerability to climate change. In South East England,

industries (e.g. breweries, agricultural enterprises and institutions such as local authorities and NGOs) perceived their operations or interests to be at risk from climate change but were concerned that their capacity to adapt to the changes was limited. Both the service sector and manufacturing businesses in Scotland were concerned about the impacts of extremes of temperature, rainfall and storms on buildings and communication structures.

In Wales, no evidence was found to suggest that businesses view climate change as an opportunity for development and expansion. In South West England, however, longer summers in the tourist season was seen as providing opportunities for economic growth, due to more visitors arriving outside the main holiday season and expected increases in year-round activity holidays.

In general, the studies recognised that identifying climate impacts on social and economic sectors was complicated and has been undertaken only to a limited degree thus far. The impacts of climate change on social and economic factors can be highly complex, and might be felt indirectly through changing structures of market demand and supply. For example, people tend to consume different kinds of products in different weather conditions and in different seasons. More fruit and vegetables are sold in the summer and beer sales rise in hotter weather, whilst clothing and footwear sales go down during hot dry summers. Authors of the North West England report viewed climate change as a valuable 'hook' by which to stimulate thinking in the business sector about the future development of society, the economy and its relationship to environmental change.

The effects on business due to interruption from extreme events (e.g. windstorm, major flooding) have been identified in some economic sectors (e.g. transport, retail). However, this information was inevitably derived from recent severe events and, as yet, the full vulnerability has not been established.

The Scotland study (the only study to address mitigation in any depth) concluded that mitigation policies for reducing greenhouse gas emissions would have a far greater impact

over the near to medium future than the direct effects of climate change.

4.1.5 Health

Headline impacts issues in studies:

- Some regions expect to benefit
- Increased health effects from dampness but reduced winter cold deaths
- Increased heat stress especially during peak holiday season
- Increased occurrence of Lyme disease

The significance of climate impacts on human health is likely to vary around the UK, but in general, few studies viewed health as the critical climate impact issue for their area when compared with impacts in other sectors. Analysis of health impacts in all studies was superficial and a unanimous call for further research to improve our understanding of this important issue was made.

Common findings emerged between studies. All areas anticipated reduced winter mortality rates, relatively small increases in summer mortality, and increased risk of respiratory problems and skin cancer owing to altered exposure to allergens and sunshine. Similarly all studies identified heat stress and discomfort as important factors to consider, and noted that occupational health could be compromised by warmer summer conditions if adaptation measures are not taken. More frequent incidence of food poisoning and outbreaks of communicable diseases were anticipated in all studies.

The North West England study concluded that health would probably benefit from climate change. Few negative health impacts were identified in South East England, a region that currently has the lowest percentage of long-term health problems in England and Wales. The Wales study, too, concluded that human health impacts would be relatively minor compared with impacts on other sectors, such as water resources and the rural landscape.

The picture presented for Scotland and South West England was more complex, with social and economic profiles influencing vulnerability to health impacts. In Scotland,

warmer temperatures are likely to benefit public health, by reducing winter mortality rates, but increased prevalence of damp (owing to increased winter precipitation) in poor quality housing stock would be detrimental to health. South West England considered itself more vulnerable to health impacts than other regions. Its ageing population will be vulnerable during the more frequent heatwaves anticipated in the future, which are also likely to occur during the peak holiday season when visitor numbers are high. Lyme disease is already more common in South West England than elsewhere in the UK and the upward trend in reported cases could continue.

4.2 Cross-cutting issues

This section covers: methods used in integrated assessment; the use of the climate and socio-economic scenarios; and stakeholder engagement.

4.2.1 Methods used in integrated assessment of impacts

This part draws upon both the sub-UK scoping studies and the sectoral studies that are developing new methodologies.

Sub-UK scoping studies

In practice, the scoping studies reviewed impacts sector by sector, but they recognised the need for assessments of climate change impacts to be conducted in a more integrated fashion. In South East England, for example, changed precipitation patterns, demand management measures, agricultural and urban run-off and increased temperatures were all considered likely to affect water quality in chalk streams. An integrated assessment of all these issues was required to provide a complete understanding of the threat posed by climate change.

In addition, there were calls for integrated assessments of the impacts of climate change on health in South West England and Scotland. Health impacts in Scotland will be integral to a host of issues including water quality, housing quality, and provision of health care services. In South West England, impacts on health will be influenced strongly

by altered lifestyles and access to health care services.

Sectoral studies

Regarding the formal framework of impact assessment, the DETR/MAFF Biodiversity Review employed vulnerability matrices that show the main species at risk, although not the full spatial distribution of potential changes. The SNH Biodiversity audit used a pressure (climate), state (habitats) and response (policy directives) framework, with spatial analogues to complement the expert judgement. Both studies identified similar habitats at most risk, notably montane, soft coastal and bog environments, and have been very useful in showing gaps in current knowledge. However, the only spatial modelling incorporated was for montane habitats within the DETR/MAFF Biodiversity Review. This study derived a threshold relationship between the distribution of montane habitats as classified in the ITE Land Cover Map, with a baseline (1961-1990) map of mean annual temperature. The UKCIP98 medium-high scenario temperature data were then used to extrapolate this relationship to the 2050s. This allowed the construction of a probability map to show those areas where the habitats were most vulnerable to change.

Both the REGIS and MONARCH projects use data-intensive quantitative modelling to ascertain the future spatial patterns of impacts, and hence the likelihood of change. These models employ recent advances in geo-computing, such as neural networks and cluster classification algorithms, to process a large amount of multivariate spatial data integrated on a uniform regular grid. This means that, for example, the SPECIES biodiversity model (employed in both REGIS and MONARCH) can incorporate complex links between variables beyond the basic deterministic link between temperature and habitat used in the DETR/MAFF Biodiversity Review study. Hence, additional inter-related factors, such as other climate variables and soil properties, are included in the analysis. The modelling methodology also means that the results are not just a projected trend from the present situation, but are independent of it, thus allowing future non-linearities to become apparent. Independent validation of model

outputs is an important part of the modelling process.

In other respects, however, modelling tools are employed differently in REGIS and MONARCH, because of the differing focus of the research in the projects. REGIS has a distinctive cross-sectoral methodology, intended to identify not just the direct climate impacts, but also indirect and secondary impacts together with potential feedback mechanisms that may link different sectors together. This is particularly important because it is these impacts which are hardest to envisage from our present-day perspective, and which therefore may not have arisen within the studies based upon expert judgement. Each of the models in REGIS has been developed independently for its own sector, therefore an important but time-consuming component of the methodology was to identify and enable the various model linkages. The models are loosely coupled and exchange information through common files. It has become apparent there is a trade-off between complexity of modelling and operations such as sensitivity/risk analysis, in that REGIS has had less scope to develop multiple-scenario combinations. Developing more compact modular systems and tighter coupling of models could improve this process in future projects, and may also reduce the time taken for model runs.

By contrast, MONARCH deals with one major sector (biodiversity) in considerable detail, modelling different ecological environments by linking them to their climatic sensitivity. The models are not directly linked, as with REGIS, because the environments are considered to be separate entities. For MONARCH, bioclimatic zoning is a first stage in identifying key species and habitats for each zone, and selected sub-areas (e.g. estuaries) are also chosen to derive results that are implied for an entire zone. REGIS, by contrast, because of its regional emphasis, covers each of its two regions comprehensively.

With MONARCH, climate is assumed to be the primary driver for change, whereas REGIS is breaking new ground in attempting to quantify concurrent changes from both climate and non-climate (socio-economic) scenarios. The latter involves constructing regional socio-

economic scenarios from the national UKCIP socio-economic scenarios, and using these to feed relevant data (e.g. the level of urbanisation) into the other models. Both projects have considerable stakeholder input to ensure the models are related to the 'real world', although this is derived at different levels. With MONARCH, the stakeholders are representatives of the various conservation bodies who require more precise spatial information on climate change impacts to inform national policy. REGIS has a wider level of stakeholder input, including representatives at a more local level, because the intention is ultimately to develop the results into a decision support system for these end-users. In both projects, stakeholder consultation involves workshops to obtain direct feedback on methodology and results.

In both projects, a geographical information system (GIS) has been successfully developed, to ensure spatial consistency of data and facilitate data integration. The GIS also provides a useful mechanism to communicate results and to develop visualisation tools for linking stakeholders with the original models via a standard interface. However, the data-intensive nature of both projects has also meant that methodological issues have frequently arisen regarding data availability and the need for common formats for data integration.

4.2.2 Use and effectiveness of the UKIP98 climate scenarios

A key component of the UKCIP's integrating framework is the UKCIP98 climate scenarios. These have established a common factor by which results from different impacts studies can be integrated and different sectoral and regional trends deduced. The scenarios have proved to be an important communication tool to promote increased awareness of the issues of climate change amongst stakeholders, by providing quantitative estimates of the magnitude of climate change within certain time periods. Guided sensitivity tests of the UKCIP scenarios have been conducted (as in the REGIS study) to compare them with other GCMs and establish their robustness. The core scenarios have been found to occupy the mid-range when compared with the full range of extremes produced by the other GCMs. By

including the ensemble scenarios, this mid-range was extended for some variables (e.g. precipitation). General opinion suggests that the range of variables and time periods included in the scenarios are robust enough for a wide variety of impact assessments. The UKCIP98 scenarios have now become the standard reference for climate change studies in the UK. Lessons learnt in their application are considered below.

Although stakeholders and researchers valued the quantification provided by the UKCIP98 climate scenarios, they found it difficult to interpret the data in a scenario concept. This was exacerbated by the fact that no probabilities are attached to the scenarios, and so each scenario is considered equally likely. The water resources sector, in particular, would prefer a more probabilistic assessment as the range of figures available in each of the four UKCIP98 scenarios implies widely differing outcomes on the likely impacts. Some stakeholders also queried the absence of a cooling scenario, which could arise from an abrupt shutdown of the thermohaline system, although this scenario is considered to be unlikely.

An emerging aspect of the use of the scenarios has been the predominance of the medium-high scenario, almost to the level of it becoming accepted as a *de facto* standard for impacts assessments. This may reflect the fact that more detailed information is available for this scenario, which has sometimes led to it being misconstrued as the most likely scenario outcome.

Studies have applied the scenarios in three ways. First, many studies have used the medium-low and medium-high scenarios, as these represent the range of climate change expected from greenhouse gas emissions scenarios in the HadCM2 model. Secondly, some have used the low and high scenarios to capture the 'full range' of possible climate changes, and from this have assessed the extremes of impacts that could result. The low and high scenarios represent the range of likely climate sensitivity beyond that of HadCM2 with lower and upper boundaries fixed at 1.5°C and 4.5°C respectively (based on IPCC guidance). Thirdly, and less commonly, a few studies have used all four core scenarios,

sometimes assigning subjective probabilities to the range.

The full ensemble scenarios are currently used much less frequently, most studies preferring to use the ensemble mean. Using the full range of ensembles would allow a better impression of the respective contributions of natural variability and anthropogenic-induced change to be obtained. In addition, very little use has been made of the natural variability 30-year model runs. An exception to this has been the work of Arnell (1999), which found that such variations for some variables (e.g. precipitation) can be very significant (as suggested in the UKCIP Technical Report). These variations may mitigate or exacerbate the impacts from climate change.

This limited use of the full range of the scenarios is particularly pertinent for the next generation of scenario development (due in late 2001), which is scheduled to increase the number of scenarios (see Section 5.1.2). Efforts are needed to develop a more probabilistic approach to scenario delivery to meet the demand for further information on their relative likelihood. UKCIP will also need to ensure studies do not develop a common wisdom and concentrate on only one of the scenarios.

Two other scientific concerns have been expressed regarding the scenarios. Reliance on the HadCM2 model for all scenarios may not be representative of the full range of climate change futures in the UK. For example, some of the other GCMs show substantially different precipitation patterns. The use of only one GCM is also not consistent with standard IPCC guidelines.

The need for downscaling has also been recognised, especially for the complex terrain typical of Scotland and Wales. However, it is not clear that a single method of downscaling is adequate, as each has benefits and constraints. The range of potential futures may remain greater, and be more important, than the calibration of scenarios to local conditions. The UKCIP2001 scenarios will be based upon the Hadley Centre Regional Climate Model (RCM) at 50km resolution.

Extreme weather events

In each of the regions, the likelihood of an increase in the frequency and severity of extreme weather events was identified as a major issue requiring further consideration. According to the UKCIP98 scenarios, increases in storminess, intense winter rainfall events, windiness, gales and summer droughts are likely to affect all parts of the UK in some way. All studies called for better information on these extreme events. Indeed, the main detrimental impact of climate change across Scotland is likely to be the change in seasonal and regional patterns of precipitation, in conjunction with more frequent and intense rainfall events. Better information on gale frequency and severity was called for in the Scotland study. Similarly, the South East England study called for a shift away from assessing impacts on average conditions towards a focus on the degree, frequency and duration of extreme events.

4.2.3 Use of socio-economic scenarios

The preparation of socio-economic scenarios for climate change impacts assessment is a relatively new development, compared, for example, to climate change scenarios. Because of its innovative nature, the development of socio-economic scenarios for the Programme has therefore taken some time, and the national level scenarios developed by Berkhout *et al* (1999) were not available for use in the early scoping studies.

There is now documented review experience relating to the application of the scenarios within the Programme in North West England (Shearlock, 2000), Wales (Vaze, 2000), South East England (Wade *et al.*, 2000) and for the REGIS study (Shackley and Wood, 2000). Some points can be made which will be fully presented in the forthcoming UKCIP Technical Report on socio-economic scenarios.

- The need to explore the social and economic dimensions of society in the 2020s, 2050s and 2080s was confirmed as being an essential part of impacts assessment. The impacts of climate change will vary widely depending on a range of socio-economic futures.

- Specific resources are needed within scoping studies to produce downscaled, regional versions of the socio-economic scenarios. Telephone interviews with stakeholders do not allow for exploration of complex alternative future worlds.
- Particular problems were faced in the regional scoping studies with their limited access to baseline data at a regional level which can be manipulated to ally with future scenarios. Consultants undertaking the REGIS project provided time to generate what was needed.
- The use of socio-economic scenarios brings into play critical social and economic framework issues for the studies which have not yet received full attention.

Next stages of the UKCIP Programme will be able to build on this early work.

4.2.4 Stakeholder engagement and awareness issues

One group of 'stakeholders' has funded studies, and a broader consultation group has provided much of the key information on which the scoping studies are based. The sectoral studies have used stakeholder workshops to develop products for the project (in the case of REGIS) and policy recommendations (in the case of the DETR/MAFF biodiversity review).

Sub-UK scoping studies

The sub-UK scoping studies have all employed extensive stakeholder input to collaboratively determine impacts based upon expert judgement. Methodologically, the stakeholder interview was the main route in most of the studies for information gathering (see Table 4.2a), but constraints are evident. This technique was considered to be a powerful way of rapidly assessing the knowledge-base of stakeholders and communicating the primary issues concerning climate change, but it had certain limitations. Five limitations with stakeholder interviews are now visible:

- The expertise on climate change impacts assessment naturally varied between regions, and was in some cases biased towards recent events.

Table 4.2a: Interviews conducted in expert consultation in regional studies.

| Study | Number of organisations interviewed |
|----------------------------------|--|
| Scotland scoping study | 102 |
| Wales scoping study | 55 |
| North West England scoping study | 148 |
| South East England scoping study | 101 |
| REGIS | 38 interviews; 100 workshop participants |

- It has been difficult to assess expert responses consistently between sectors.
- Success of a particular interview was highly dependent on the knowledge of the stakeholder and the context of that sector.
- Respondents from sectors with short planning horizons had not considered longer-term changes, and therefore had difficulty conceptualising some future impacts.
- Studies varied considerably in the way interviews were conducted.

Stakeholder interviews allowed the main regional impacts to be identified for each sector, together with an assessment of the sensitivity and vulnerability of those sectors. If possible, potential benefits from climate change were derived during the studies, and information on potential adaptation strategies for each sector was also collated. In addition, some regions carried out a literature survey that identified possible impacts predicted by scientific and socio-economic studies relevant to the regions. Cross-sectoral impacts were analysed for some studies by constructing two-dimensional tables linking the potential influence of one sector on another, although no formal framework was established for this work.

The North West England scoping study followed an innovative strategy in identifying likely sensitivities and relative magnitude of impacts within 'landscape domains', some of which overlapped so that they were not mutually exclusive. This assisted in identifying cross-sectoral and sub-regional patterns that were often not as explicitly defined in other regions. Studies also varied in their form of stakeholder engagement, whether face-to-face, by telephone or by written questionnaire, which had an impact on response rates and coverage of sectors. The South West England study differed from others by having no formal study but eliciting

stakeholder opinion during the course of a major conference and workshops, with results summarised afterwards. The methodology employed by the Scotland study also varied because it included mitigation issues.

The UKCIP98 climate scenarios were considered vital for providing a 'vision of the future' to stakeholders, but in practice were only discussed superficially at interviews. An awareness of the general sensitivity of stakeholders to climate change was needed before their sector's vulnerability to specific impacts could be properly evaluated. A perceived problem is that stakeholders' views were often coloured by unscientific press reports rather than clear and objectively-based scenarios presented by the study team. The scoping studies varied in their quality and in the expertise available to review specific sectors. In order to help frame reactions on adaptation responses, interviewers occasionally discussed scenarios of impacts with stakeholders as if they were formal predictions with some confidence. Although this may not have been the intention, it is often implied by generalisations such as 'agriculture will suffer from reduced precipitation and increased evapotranspiration'. The result is a 'common wisdom' about impacts becoming accepted as well-documented fact, and then as the basis for action. This may give the impression that further research is unnecessary since we already know what the impacts will be.

Several studies emphasised the need for improving stakeholders' knowledge of climate change. In Wales, recommendations are being made to the National Assembly to set up a forum of local stakeholders and experts: to exchange information, concerns and ideas; to act as a focus and facilitator for the climate change debate; and to start building the networks which are needed to underpin integrated planning.

The experience of the North West England study team strongly suggests that past extreme weather events act as the ‘hook’ by which stakeholders become aware, and think through the impacts of climate change. Extreme events with negatively perceived impacts have been drivers for policy change in the region. Many environmental managers suggested that firms would probably be motivated to invest resources in responding to climate change should extreme events become more frequent, as is expected. However, strong evidence that weather-related extreme events are changing would be required before action incurring a financial outlay would be undertaken.

Specific issues about the difficulties in engaging stakeholders from the business community were noted in Section 4.1.4. A general conclusion from the regional studies was that the impacts of climate change on society and the economy are more difficult to quantify and less well understood, than impacts on the natural environment. For most stakeholders, over the next 50 to 100 years socio-economic changes were considered to be of greater significance for business than climatic changes. It was felt that this community would relate more readily to climate impacts presented for the next 10 to 30 years, rather than on longer time-scales.

Within the public services sector, climate change issues are not generally afforded a high priority, with the exception of the water companies and water authorities. Only a small minority of local authorities, usually led by enthusiastic individuals, has become actively involved. For local and public health authorities, numerous competing claims on resources and existing financial structures result in low stakeholder engagement in climate change issues.

The North West England study concluded that stakeholders rarely saw climate change as a key driver of change, but suggested that an informal trade-off may exist between uncertainty and vulnerability. Since climate change has been modelled with more certainty than most other long-term issues (e.g. socio-economic changes) it could provide an ‘island of certainty’ into the future, which may then help organisations plan into the future on other issues as well. This may elevate assessment of

the impacts of climate change beyond that arising from evaluation of vulnerability alone.

In Wales, recommendations are being made to the National Assembly and other organisations on how to increase public awareness of climate change issues. With reference to the financial implications of forthcoming climate mitigation strategies in Scotland, a need was identified for a better understanding of public perceptions of climate change issues. In particular, public awareness and acceptance of the necessity for the imminent costs of climate mitigation and adaptation, to minimise detrimental climate impacts in the future, must be appraised. The South East England study highlighted the importance of raising public awareness of climate change in the following ways:

- Water resources: ‘Water-wise’ campaigns to reduce water use in gardens.
- Changing countryside: Education on the potential losses and changes in the countryside due to climate change.
- Coastal management: Improving awareness of the risk of floods among people living in tidal floodplains.

Overall, the scoping studies concluded that greater certainty in climate predictions and impacts, more information on extreme events and more spatially explicit information, is required across the UK to communicate the impacts message and to mobilise adaptive responses. This call was made by all studies, particularly Wales and Scotland where it was argued the UKCIP98 climate scenarios do not shed light on regional variations of precipitation. Scotland also called for more research into the potential impact of a changing ocean circulation, of which little is currently known. Further information on changes to wind patterns under climate change was also considered vital.

4.3 Summary and synthesis of conclusions from studies

This section contains summaries of adaptation issues arising from the studies and recommendations for further research. A summary table (Table 4.3a) is also provided.

4.3.1 Summary of adaptation issues arising from studies

Institutional approaches to adaptation

An over-arching adaptation theme emerging from all regional studies was the need for a more holistic, integrated approach to planning policy, and for climate change to be incorporated into this process. Coping with, and adapting to, a changed climate involves overcoming institutional inertia and promoting cultural change above all else. Climate change demands a type of long-term strategic planning which has not only been absent so far in the private sector but also lacking in the public sector. Because of the interconnections, more effort will have to be made to establish 'joined-up thinking' and 'integrated planning'.

This approach was considered particularly important for installations that have long lead times and life spans. In South East England, for instance, the study states that proposals for new housing or industrial development should be appraised in the light of factors affected by climate change, such as flood risk and the availability of water resources. The South East England study strongly recommended that revisions to the planning process are needed to restrict new development in coastal floodplains. A pragmatic suggestion made in the study was that water companies should be statutory consultees in the planning process.

Schemes currently exist to exemplify this integrated approach. Agri-environmental schemes operational in Wales, such as Tir Cymen and Tir Gofal, call for planning and decision-making across sectors. The National Parks, which constitute a considerable percentage of the land area of Wales, typically think and plan across sectors and on long time scales. Guidance on best practice for integrated planning could be obtained by examining these cases.

Extension of pioneering schemes such as Tir Gofal can provide the framework to resolve conflicts between different sectors that will inevitably arise with climate change. In addition to agriculture and biodiversity, other important sectors in the rural environment, such as forestry, cultural heritage, tourism and recreation should be included.

An example of the need for integrated planning was also provided in the Scotland study. Climate change is not expected to be a key driver of change in Scotland's domestic sector. Instead numerous interwoven factors such as poor housing stock, fuel poverty, public health, and energy efficiency will drive change in the domestic sector. The study calls for future planning of housing to include an assessment of climate risks, with closer co-ordination between insurers, planners and the Scottish Environment Protection Agency (SEPA).

The Wales study called for changes to policy, to improve planning decisions. The study included recommendations for climate change to be considered as a component of sustainability (which is a key cross-cutting theme for the National Assembly) in determining policies. Innovative strategies, which take account of the interactions between climate change, agriculture, conservation and water resources, were called for. The study also recommended that climate change should be factored into planning guidance (Technical Advice Notes), notably in areas prone to flooding.

There was a perceived need in South West England and Wales to rationalise the current split in responsibilities for flood and coastal defence and to work towards more integrated management of these issues. In these two areas of the UK, a relatively high proportion of coasts and land is currently designated for environmental protection. Such sites are considered to be particularly vulnerable to climate change impacts. Factoring climate change into criteria for site designation was seen as an important step towards protecting, or managing, these landscapes in a changing environment.

The North West England study emphasised the usefulness of policy measures to reduce vulnerability to climate change in the countryside. For example, policies for upland land management can limit erosion and stress upon vegetation, hence decreasing the vulnerability of uplands to future climate change.

One adaptation strategy to take account of climate change that was suggested in North West England was the inclusion of 'climate change headroom' in planning for new

facilities. Planners in the water industry currently use this concept to take account of uncertainty in future demand and supply. The allowance for sea level rise that coastal engineers are advised to include in the design of new coastal and tidal defences is another form of climate change headroom. The North West England study suggested that the climate change headroom concept could be extended to include issues such as waste water management, working conditions, insurance, cooling requirements and process design. On a similar theme, the Wales study recommended that climate change should be incorporated into building regulations to ensure that they address potential climate change impacts during the lifetime of the structures being planned. The South East England study called for climate change to be factored into the planning, design and construction of houses. Building Regulations already factor in the requirement to protect new structures from clay shrinkage, but there may also need to be amendments in the future to ensure they are adequately ventilated and able to withstand higher rainfall and windspeeds.

As a tool to aid land use planning, both the Scotland and South East England studies suggested that maps indicating exposure to climate impacts would be beneficial to local authorities and other organisations. The Environment Agency's Indicative Floodplain maps are now being used in this context, although these are based on current flood recurrence levels and risk; the point is made that historical data on vulnerability to flooding should not be relied upon. The likelihood is that current defences will have to be improved to mitigate against the increased risk.

The North West England study had additional advice for organisations considering how best to adapt to climate change. The study advised that they should adopt an incremental experience-based approach. They should monitor the effects of climate change upon operations, systems and markets in a sequential fashion and should also be 'light on their feet', and be prepared to reassess decisions and institutional arrangements in response to climate change. This advice has resonance with the Wales study, where it was felt that institutions would struggle to adapt to climate change, owing to institutional inertia, conflicting priorities, lack of certainty in the

climate predictions and disparity between planning and climate change time-scales.

Planning horizons will need to be meshed together, according to stakeholders consulted in the Wales study. Corporate strategic plans work on 3 or 5 year time frames, land-use planning operates up to 15 years ahead, revenue and flood defence planning to 5-10 years ahead, whilst infrastructure is planned for extreme events on historical time frames. These short time-frames are problematic for climate impacts assessment as the climate scenarios work to 30 year time sets and are not yet robust for these short time frames.

Climate change will have to become part of the currency of every decision-maker, not just the experts. Not only will new problems have to be faced but old problems may re-emerge, such as the remobilisation of metalliferous and toxic wastes as a result of increased precipitation and flooding. In order to assess how climate change will interact with existing problems, sound baseline information is required.

Specific adaptation issues for each sector are discussed below.

Water resources

Headline adaptation issues in studies:

- Availability of water resources included in planning for new housing and industrial development
- Inclusion of 'climate change headroom' in managing water resources
- Water companies to be statutory consultees in planning process
- Possible need for increased transfers of water
- Possible need for increase reservoir capacity
- Water efficiency schemes
- Strategies to manage risk (e.g. drought and outage contingency planning, emergency response tools)

Every region has a water impact of concern: paradoxically both too much and too little.

South East England, in particular, expects problems in meeting growing demands for

water resources under climate change. The scoping study stated that, while adaptation options are well defined, they may be difficult to implement and will be expensive, making this sector very vulnerable to change.

The anticipated demand for new households in South East England in the coming decades is expected to place additional pressure on water resources in the region. To meet this demand, while maintaining summer flows in rivers and water levels in wetland sites, there may be the need for an increase in transfers within the region and from outside. Furthermore, there may be pressure from water companies to increase the number or size of reservoirs, to store winter rainfall. Other adaptation measures proposed in the study included water efficiency schemes and grey water recycling.

The South East England study emphasised the importance of strategies to manage the risk of water shortages. These should include drought contingency planning, emergency response tools and outage contingency planning.

Conversely, the study in Wales found that water resource issues may assume a strong political dimension, since, in the longer term, there may be pressure to build reservoirs in Wales to supply consumers in England. Increasing reservoir storage capacity in North West England may be an effective response to excess winter rainfall and reduced summer precipitation.

Water resources is one issue where a national framework needs to be considered before adaptation measures can usefully be finalised at a sub-UK level.

Flooding and coasts

Flood defence looks set to become a major issue in all areas, with the Wales study identifying a need for clearer and more transparent presentation of responsibilities and stating that financing is needed for effective adaptation. Both the Wales and South East England studies called for the need for revised planning guidance to restrict development in flood prone areas, either close to rivers or along the coast (this is being addressed under PPG25 which is currently at the consultation stage). The South East England study also identified the possible need for some existing

Headline adaptation issues in studies were:

- Integrated management of flood and coastal defence, incorporating heritage and ecology
- Revisions to planning process to restrict new development in coastal floodplains
- Continue to apply climate change 'headroom' in planning flood defence, but keep under review with regard to improved data
- Improved floodplain mapping to aid planning
- Possible relocation of industries in coastal zones
- Upgrade waste water and stormwater systems
- Consider managed retreat of coastal defences at some sites

industries in coastal zones to re-locate. Once again, the need for integrated assessment of flood defence schemes, to incorporate heritage and ecological issues, was highlighted in South East England.

Scotland and North West England identified the threat that increased flooding poses to waste water and stormwater systems. Upgrading these systems to take account of climate change will be expensive and will require extensive forward planning.

South West England called for further research to inform adaptation decisions on the erosion of coasts and beaches, where it was felt that a careful balance would be needed between protecting certain assets and retreating from others where costs of sustaining coastal defences or replenishing beaches become uneconomic.

Whilst some strategic types of adaptation measures can be readily implemented, such as the incorporation of climate change in all existing mechanisms of coastal planning and management, both hard engineering works and managed retreat options require more information at a local level before action is prudent. Both from the review of work which has been undertaken outside the UKCIP (Appendix 1) and from the REGIS study, it can be seen that filling all these gaps would be no mean task. Priorities for more work need to be determined. A massive scaling up of effort is needed to get the necessary data-sets into

accessible formats and to derive climate data which can model regions and extremes events better. Not the least of these issues is that work undertaken up to now needs to be firmly brought within the public domain and made accessible to non-expert decision-makers.

The changing countryside

Headline adaptation issues in studies were:

- Upland land management to limit erosion and stress upon vegetation
- Factor climate change into criteria for site designation, to help protect or manage important habitats/landscapes
- Planning proposals to consider need for habitat corridors
- Encourage farmers to capitalise on positive opportunities
- Develop and plant new crops

Impacts of climate change are most powerfully expressed, in terms of raising awareness amongst the public, through the changes to the areas where people live and go to enjoy themselves. The sub-UK scoping studies have brought out the significance of this issue. Although the broad changes to agriculture, forestry and biodiversity which can be expected in the UK have been covered in work previous to the UKCIP, investigations on the broader countryside have formed an important part of work within the Programme. Vulnerable areas have been identified in all studies. Whilst agriculture is generally considered adaptive to climate change, each study brought out an issue that would be difficult to respond to.

The South West England study was upbeat in its ideas on how land use and the rural economy should develop in response to climate change, stating that enterprising farmers and landowners should be encouraged to capitalise on the positive opportunities presented by climate change.

High levels of development and variable geology in South East England mean that there are limited 'escape routes' for plants and animals migrating in response to climate change. It was therefore suggested that planning proposals in the region should consider the need for habitat corridors.

Results emerging so far suggest that decision-makers face challenges to their accepted ways of operating. The studies show that existing policy frameworks such as landscape protection measures, biodiversity conservation systems and agri-environmental schemes will need to facilitate adaptation. More positively, existing frameworks mean that mechanisms are potentially available which can be modified to facilitate adaptation.

Business sector

Headline adaptation issues in studies were:

- Inclusion of 'climate change headroom' in decision making
- Review Building Regulations
- Avoid unsuitable locations
- New business growth (e.g. environmental consulting, technological solutions, construction, eco-tourism)

So far, work within the UKCIP has failed to significantly systematically engage the business community outside the water and insurance sectors (which are already well-informed). There are several reasons for this situation.

- Resources available to the study teams did not in all cases allow time for in-depth development of a relationship with the business constituency. Large organisations have managers responsible for environmental affairs of which climate change impacts is just one item. Most SMEs cannot afford staff time to go to steering committees and workshops.
- Some large and multi-national companies which do work to long planning horizons prefer to address the issue as a strategic, commercially sensitive issue and do not see the benefits from working with others. It is, however, of some surprise that in certain cases, whilst 'green' credentials can apparently be gained by developing an 'open' approach on mitigation issues, little kudos is perceived in working on direct physical impacts of climate change.

Nonetheless, some important findings have emerged from consultation within the sector. It is evident that the adaptive capacity of the business sector will be influenced by two key factors: the time-scale of operation and the

resource base of the affected business. The South West conference noted that ‘Within businesses a two year plan is rare and a 20 year plan unreal’ (Russell, 2000). Climate change demands a complete change to planning horizons for many firms. Developing climate predictions over the next 10 years, in addition to the longer-term scenarios may help to address this. Industries with planning horizons of over 20 years, such as the utilities, were considered to be in a good position to develop adaptive strategies. However, smaller businesses that operate on shorter time horizons and smaller budgets are not likely to consider climate change in their planning and so may be vulnerable to change.

Respondents in the South East England business sector felt that most businesses can respond to the impact of climate change flexibly and incrementally. For example, in a scenario where climate impacts render a specific region unsuitable for operation (e.g. water intensive processes such as brewing or pulping paper), businesses may simply relocate. This would have significant impacts on local economies.

Relocation of businesses were not considered likely in Wales, and the ability of its institutions to adapt to climate change might be further hampered by the relatively low GDP and poorer skills base in comparison to other parts of the UK. The Wales study recommended that corporate strategic plans should incorporate a wider range of issues than they do at present, due to the high degree of interaction between sectors that will be affected by climate change.

The North West England study supported the view that market conditions will have a major influence upon vulnerability to climate change and adaptive capacity. If markets are buoyant, for example, extra investment to adapt plant to climate change can be afforded.

The South West England conference had a positive approach to adaptation of businesses under climate change. The region identified the need for businesses to make the most of the opportunities presented, in terms of: the provision of climate change services, e.g. environmental consulting; the provision and installation of technological solutions, e.g. construction; and the provision of retail and

services associated with lifestyle changes. However, South West England also identified potential pressures on utilities and infrastructure if climate change leads to greater visitor numbers in the region. One suggestion to alleviate this potential impact was not to attempt to restrain the growth of tourism *per se* but to improve spend per visitor. Another suggestion was to look at ways in which eco-tourism in the region could be promoted.

Health

Headline adaptation issues in studies were:

- Integrated approach to monitoring impacts (health outcomes) and exposures (e.g. air pollution, water quality)
- ‘Win-win’ strategies (e.g. improving quality of housing will also improve health)

A call was made by all sub-UK scoping studies for further research into health impacts. Better certainty in climate impacts assessments was considered essential for informing responses. While one study (South East England) suggested such analyses should be conducted at national rather than regional level, another (South West England) recommended regional health impact assessments to develop appropriate adaptation strategies.

All studies presented a strong argument for the adoption of an interdisciplinary approach towards assessing impacts, developing responses and reducing vulnerability of human health to climate change. An integrated approach to monitoring impacts (health outcomes) and exposures (e.g. air pollution, water quality) was called for, with links to programmes in other countries.

‘Win-win’ adaptation strategies were highlighted in Scotland, where improving the quality of housing stock will improve the thermal qualities and state of repair of properties, (thus reducing emissions and minimising detrimental impacts of climate change) and will also improve health.

Public awareness of potential health impacts should be increased, as many risks can be avoided with simple behavioural changes.

Summary

Results of the detailed consultations undertaken in the sub-UK scoping studies presented in this section provide clear guidance on how adaptation to climate change could be motivated and initiated.

- a) There is need for better communication and awareness-raising about the potential impacts of climate change and the need for adaptation responses in sectors which have short term planning frames and whose normal activities do not involve dealing with the physical environment. Organisations need to see the opportunity costs and other benefits from their investments. (This principally involves businesses in the manufacturing and service sectors and the tourism industry).
- b) Informed sectors, (such as water and other utilities, and environmental protection) have indicated that the barriers to taking adaptive actions are: the lack of financial resources to speed up programmes of physical infrastructure; the need for political will to overcome institutional inertia and create these resources. There is also a strongly perceived need for more certain information about impacts before significant action can be taken. There are significant implications for resources for all organisations in the public and private sectors.

It should, however, be emphasised that these adaptive responses have tended to consider only "well-behaved" climate change. Non-linear changes in the climate could require different approaches to be adopted.

4.3.2 Recommendations for further research

The sub-UK scoping studies have identified a range of subjects where further research is required, and these recommendations can be summarised by topic.

- a) *Downscaling of climate models.* A strong common factor to emerge from all studies is the need for more explicit spatial data from the climate scenarios. Each study identifies the need for GCM results to be downscaled for

their area, either via Regional Climate Models (RCMs) or statistical methods. Wales and Scotland, in particular, identified variation in their regional climates as a major issue. It has also been suggested that medium-term (decadal) projections of future climate may be very useful for stakeholders, such as in the business sector and utilities.

- b) *Extreme events.* A common research requirement is the need for more information on the likelihood of an increase in the frequency and magnitude of extreme events, such as storm surges and wind storms. More spatial detail is required, emphasising the link that needs to be made with research on RCMs. The Scotland study advocated linking the availability of better data to the development of risk maps. The South East England study proposed more research on establishing impacts of extreme events on urban areas. Such data would assist in refining the current levels of risk assessment.

- c) *Monitoring and regional indicators.* The need to develop future research programmes to provide better environmental monitoring and longer term data-sets was highlighted. For example, South West England advocated better use of the historical record to establish the context of extreme events. A related issue is the need for better regional indicators of climate change. Both the Wales and the North West England studies proposed developing more specialised local indicators. The Scotland study identified data availability and the need for a metadata repository (containing possible indicator information) as a major research objective.

- d) *Socio-economic models.* Although studies suggested the need for more research distinguishing climate and non-climate impacts, recommendations differ when proposing the type of research required. The economy in Wales is advocated to be sufficiently distinct from the rest of the UK to require local socio-economic scenarios. Other studies are more concerned with the relative importance of climate versus socio-economic drivers and their influence on regional land use models. The studies recognised that the impacts of climate change on social and economic factors can be highly complex, and might be felt indirectly through changing structures of market demand (e.g. consumption

of different kinds of products in different weather and seasonal conditions). Relationships between business operation and climate impacts are highly tentative, and disentangling the influence of other socio-economic changes makes identifying causal relationships problematic.

e) *Water resources and hydrology.* This is identified as another research topic requiring more local information. Changing precipitation patterns, demand management measures, agricultural and urban run-off, and increased temperatures will all influence water quality. Impacts of changes in each variable are known, but the collective impacts of all these changes have yet to be assessed. In the South East England study, more work is suggested on the combined effect of these factors on the quality and ecology of the region's chalk streams. Integrated catchment studies that consider water balance, water quality and ecological change are proposed by all studies. Changes in domestic, industrial and agricultural demands for water in a changing climate also require further research. Finally, improved approaches to floodplain mapping are recommended.

f) *Coasts.* All studies presently completed have had a significant coastline and have therefore identified this as a target area for further research because of the high level of uncertainty in predicting local impacts. In addition to coastal flooding, more information on erosion and changes in the wave regime are required. The need to relate this to other research, such as extreme events and ecological studies, is emphasised.

g) *Marine environment.* Both the Scotland and South West England studies identified the vulnerability of the fishing industry to climate change. The need for further research into changing marine conditions, notably the pattern of ocean currents was highlighted. This also has major implications for UK biodiversity.

h) *Biodiversity.* Further research on vulnerable species and habitats that are of national or international importance in each region is a common theme. Freshwaters, upland habitats, and the marine environment (especially in the South West England and Scotland studies) are advocated as major

research areas. There was also felt to be a need for further research on interactions of agriculture and forestry, for example with factors such as nitrogen deposition, acid rain, ozone and overgrazing, and how this relates to management practices.

i) *Agriculture and soils.* Several aspects of the agricultural sector were identified as requiring further research. Undoubtedly, research into new crops will continue but it is suggested that there also needs to be related work on the influence of these on soil microbial activity and changes in nutrient cycling. Pests, availability of adequate grazing land, peat soils and potential changes in agricultural run-off are also topics recommended for further research. In addition, there are numerous inter-related and poorly-researched factors related to agricultural changes which remain to be tackled such as water quality, biodiversity and socio-economic implications for rural communities. Similarly, in the forestry sector, changing species and resulting land use impacts in each region need further research.

j) *Uplands.* These have been identified as particularly vulnerable areas. Climate change could potentially cause significant shifts in species and vegetation types. In addition, the changing pattern of agriculture and forestry (both climate and non-climate induced) will result in other secondary effects on the landscape.

k) *Regional industrial base.* Likely changes to core industries was a common issue which it was suggested should be linked with improved information from sources such as RCMs and socio-economic models. Hence, the North West England study recommended further research on changes in manufacturing industry, whilst the South East England study proposed research on service sector SMEs, South West England and Wales studies required further information on potential loss of regional advantages (e.g. in agriculture), and the Scotland study was concerned about the shifts in the west/east regional pattern of industry and impacts on fisheries.

l) *Health.* Studies generally felt that more research needed to be carried out into issues such as new diseases and respiratory problems from poorer air quality. The potential risks

need to be quantified and placed more in the public domain, and links to other country programmes established.

m) *Tourism*. More research on potential changes in tourism and the cultural heritage were advocated by all studies, especially South West England. It was felt that this was an under-researched topic at present, with few studies investigating the link between climate change and the effect on visitor numbers and sites. Potential influences on changed seasonal patterns were also unclear.

4.4 References

Arnell, N.W. (1999). *Effects of global warming on water resources: implications of multi-decadal variability and changes in year-to-year variability*. Report to Environment Agency. Department of Geography, University of Southampton.

Shackley, S. and Wood, R. (2000). *Socio-economic scenarios for use in regional climate change impact and response studies in East Anglia and the North West of England*. Paper presented at the UKCIP workshop on socio-economic scenarios, Linacre College, Oxford. 23 February 2000.

Shearlock, C. (2000). *Operationalising the 'SPRU' scenarios in the North West of England*. Paper presented at the UKCIP workshop on socio-economic scenarios, Linacre College, Oxford. 23 February 2000.

Russell (2000) *The Climatic Challenge Conference: Conference Proceedings*. Report from Working Group 4: Business, Finance and Insurance.

Wade, S., Sutherland, D. and Barber, J. (2000). *Socio-economic scenarios for climate impacts assessment. Application of scenarios in the South East England scoping study*. Paper presented at the UKCIP workshop on socio-economic scenarios, Linacre College, Oxford. 23 February 2000.

Vaze, P. (2000). *Socio-economic scenarios for climate impact assessment*. Paper presented at the UKCIP workshop on socio-economic scenarios, Linacre College, Oxford. 23 February 2000.

Table 4.3a Summary of key issues from scoping studies

Key: SW = South West England; NW = North West England; SE = South East England

| Topic Area | Water resources and quality | Flooding and coasts | Countryside | Business | Health |
|---|---|---|--|--|--|
| Key impacts of climate change | <ul style="list-style-type: none"> Meeting summer demand with reduced and more variable precipitation, and coping with heavier winter rainfall Shortages in SE, Wales High winter rainfall (NW) Waste water treatment Reduced water quality in rivers (e.g. chalk streams in SE) Providing industrial supply, especially to SMEs dependent on water, breweries and paper mills (SE) | <ul style="list-style-type: none"> Coastal flooding affecting housing, industry, biodiversity, transport infrastructure, utilities, especially on coastal estuaries (e.g. Loughor, Mersey, Arun, Scottish firths), low-lying land (e.g. Gwent Levels, Somerset Levels), steep-sided valleys (Polperro, SW) Impacts of sea level rise, increased storminess and altered wave energy on important ports (Heysham, NW; Dover, SE) Disruption to railway lines and coastal industry (SW; NW; Scotland) Fisheries in SW and Scotland e.g. declines in migratory salmon Coastal erosion (SW) | <ul style="list-style-type: none"> Loss/reduction of rare or important species (e.g. Snowdon Lily, dipper, snow bunting) Benefits to some species (Adonis blue butterfly and lowland grass orchids, SE; Speckled wood and comma butterflies, NW) Habitats – drying of heathland (SE), uplands and wetlands (Wales), Cairngorms (Scotland) Coastal squeeze results in loss of mudflats and salt marsh (e.g. N Kent coastline) Changes in agriculture – new crops (e.g. Navy Beans, SE and SW), more arable in Wales Summer drought (SE) and heavy winter rains (NW) pose difficulties for farmers Forestry expected to benefit but increased risk of fires and pest damage | <ul style="list-style-type: none"> Generally low awareness of possible impacts Industries reliant on water could suffer (SE) Opportunities for growth in tourism and leisure (SW) Insurance – more weather-related claims | <ul style="list-style-type: none"> Some regions expect to benefit (NW) Increased health effects of damp but reduced winter cold deaths (Scotland) Increased heat stress especially during peak holiday season (SW) Increased Lyme disease (SW) |
| Regional significance | <ul style="list-style-type: none"> High in all areas | <ul style="list-style-type: none"> High in all areas | <ul style="list-style-type: none"> High in all areas | <ul style="list-style-type: none"> Unknown in many areas Benefits to tourism (SW) High for insurance industry | <ul style="list-style-type: none"> Medium in SW, Scotland Lower in NW, SE |
| Adaptation measures and strategies | <ul style="list-style-type: none"> Availability of water resources included in planning for new housing/ industrial development Inclusion of ‘climate change headroom’ in managing water resources Increase transfers of water? Increase reservoir capacity? Water efficiency schemes Strategies to manage risk, e.g. drought and outage contingency planning, emergency response tools | <ul style="list-style-type: none"> Integrated management of flood and coastal defence, incorporating heritage and ecology Revisions to planning process to restrict new development in coastal floodplains Water companies statutory consultees in planning process Inclusion of ‘climate change headroom’ in planning flood defence Floodplain mapping to aid planning Relocate industries in coastal zones? Upgrade waste water and stormwater systems Protect coasts suffering erosion, or retreat? | <ul style="list-style-type: none"> Upland land management to limit erosion and stress upon vegetation Factor climate change into criteria for site designation, to help protect or manage important habitats/landscapes Planning proposals to consider need for habitat corridors Encourage farmers to capitalise on positive opportunities Plant new crops e.g. Navy beans and sunflowers | <ul style="list-style-type: none"> Inclusion of ‘climate change headroom’ in decision making Review Building Regulations Avoid unsuitable locations Growth in businesses e.g. environmental consulting, technological solutions, construction, eco-tourism | <ul style="list-style-type: none"> Integrated approach to monitoring impacts (health outcomes) and exposures (e.g. air pollution, water quality) ‘Win-win’ strategies: improved quality of housing will also improve health |
| Cross-cutting issues | Studies called for integrated assessments of impacts to take account of interactions between different sectors. An integrated approach to adaptation measures and strategies is also essential. | | | | |
| Future research | <ul style="list-style-type: none"> Integrated assessment of effects of changed precipitation, demand management measures, run-off and temperatures on water quality Integrated catchment studies Changes in domestic, industrial and agricultural demand Improved floodplain mapping | <ul style="list-style-type: none"> Improve predictions of local impacts of flooding More information on erosion and changes in wave regime Incorporate consideration of extreme events and ecological studies | <ul style="list-style-type: none"> Vulnerable species and habitats, including freshwaters, uplands and marine environment Interaction of biodiversity, agriculture, forestry, water quality and socio-economic impacts Influence of new crops on soil microbial activity and changes in nutrient cycling Effects of climate change on pests and soils Land use impacts of forestry changes | <ul style="list-style-type: none"> Impacts of climate change on core industrial sectors (e.g. service sector SMEs, agriculture, fisheries and tourism) Potential changes in tourism and cultural heritage | <ul style="list-style-type: none"> New diseases Respiratory problems from poorer air quality More quantification of health risks |
| Cross-sectoral research requirements | <ul style="list-style-type: none"> More explicit spatial data on climate scenarios: RCM results to be made available for each area More information on frequency and magnitude of extreme events under climate change Better regional indicators of climate change, better environmental monitoring and longer term data-sets More socio-economic studies, e.g. local socio-economic scenarios, assess relative importance of climate vs. socio-economic drivers and their influence on regional land use | | | | |

Chapter 5

Recommendations for Future Research

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5.1 Future research activities of UKCIP

5.2 Research for next stage work on impacts and adaptation

5.3 Conclusions

5.4 References

Annex 5.1: Further details on the research agenda

This chapter contains two parts: it identifies possible future research activities of UKCIP and future research needs for the UK national assessment. More detail is provided on the future research needs in Annex 5.1.

5.1 Future research activities of UKCIP

5.1.1 Undertaking of UKCIP studies

At this three year review stage, it is an appropriate moment to take stock and determine how the research activities of UKCIP should be focused in the next stage. Table 5.1a provides an overview of the stages of impact and adaptation studies to provide a reference framework.

As the UKCIP moves towards its next phase of operation, with a portfolio of projects leading from qualitative scoping studies to more detailed quantitative research into key topics, methodological issues and quality assurance will become increasingly important. These include:

- Choice and use of models;
- Data: access and quality;

- Scenarios, both of future climates and the context of socio-economic conditions

Possible next stage work for consideration

- The UKCIP could identify the key models and methodologies available in the UK and match their potential application against user requirements in different sectors. A need to disseminate best available practice should assume a higher priority within the Programme.
- To strengthen the assessment stage, it would be useful if ground-truthing of model development were enabled. This could be by peer review or possibly the commissioning of additional work, to produce complete documentation of the model assumptions and structure.
- Consideration could be given to strengthening the UKCIP's role in improving the robustness and depth of studies, particularly once studies are commissioned. A template of criteria for example, could provide the attributes of different modelling approaches and their utility for different classes of problems.

Table 5.1a: Stages of climate change impact and adaptation studies

| Stage | Central question | Research method | UKCIP progress |
|--|---|--|---|
| Issue attention; stakeholder engagement | <i>Is this an issue?</i> | Extreme scenarios, observed trends, expert opinion | Workshops, meetings, presentations |
| Issue identification | <i>What are the issues?</i> | Research synthesis, expert opinion, stakeholder interviews, local interpretation of regional reports, vulnerability profiles | Scoping studies |
| Priority setting | <i>What are the priorities?</i> | Expert elicitation, criteria rating/ranking, workshop processes | Not done in a formal process, except for Biodiversity Reviews |
| Impact assessment | <i>How serious are the expected impacts?</i> | Formal modelling, linked sector models, scenario evaluation | REGIS, MONARCH |
| Adaptation evaluation | <i>What options should be adopted?</i> | Decision analysis, risk assessment | Risk Study currently in progress |
| Integrated assessment | <i>What are the effects and responses across sectors and at the regional scale?</i> | Integrated assessment modelling and stakeholder engagement | Initial methodology being developed by REGIS |

- Translation of the scenarios into probabilistic distributions, even with quite a large range in the probabilities, would be very useful, as would using additional GCMs from the IPCC suite.
- Ideally, the outcome of an assessment process should allow sufficient time for a variety of stakeholders and experts to review the results, suggest improvements to the models, recommend additional scenarios, and report results against the realities of decision making at the sectoral or regional level.

5.1.2 Improvement of UKCIP tools

When stakeholders opt to use UKCIP technical products for their work, it provides an easy route for UKCIP to achieve co-ordination. It is therefore vital to maintain the flow of good quality products for the Programme. The UKCIP98 climate scenarios in particular have provided leadership for the Programme and are also widely used in many specific pieces of research not formally within the umbrella of the Programme. The socio-economic scenarios will shortly be released in the form of a technical report and have already begun to be used. New studies underway on risk and uncertainty in decision-making and costing impacts are also intended to develop methodological tools for the Programme.

The present review has shown that decision-makers seek further guidance and more information on climate change. New ideas for products to strengthen the Programme in its next phase are therefore identified here. Box

5.1a also summarises key recommendations from completed scoping studies.

Development of the UKCIP climate scenarios

As discussed in Section 1.2, the new UKCIP2001 climate scenarios, commissioned by DETR, are being developed to meet the needs of the user community. These are intended to provide more detail on extreme events and improved regional predictions of climate change by using the Hadley Centre Regional Climate Model (RCM) with a high spatial resolution (50km). Daily data (as well as monthly data) will be generated for some key variables, which will assist in the assessment of low-frequency high-magnitude impacts. Even using regional models, however, the credibility of changes in extremes will require a thorough validation.

An extended 1961-1990 baseline climatology, probably at 5km resolution, will also be released with the new scenarios. This climatology will contain additional variables and full monthly time series data for some parameters.

The scenarios will be available towards the end of 2001, and should also provide an impetus for more detailed quantitative studies based on the extra precision that they provide.

Model validation and verification

Validation will remain on the research agenda as a necessary step to ensure impacts predictions for the future have a sound scientific basis. Potentially, benchmark data-

Box 5.1a: Key recommendations for further action in specific completed first phase studies

- The development of 'regional' indicators and monitoring systems, particularly of sites at most risk (Wales, South East England)
- A massive scaling up of effort to get the necessary data-sets in all sectors into accessible formats, build meta-data depositories, and to undertake intelligent downscaling of climate data. (Scotland, Wales, South East England, North West England)
- More resources into stakeholder awareness and information dissemination (all studies, particularly Wales)
- Develop socio-economic scenarios at a regional level (Wales)
- Learn how to deal with uncertainty and explain it (South East England study)

sets could be compiled to assist in the process. Development of common baseline data for projects would also facilitate validation. Formal sensitivity testing is standard practice, but not always reported adequately. External scientific advice and review is also critical, and review experts could be formally integrated into the project methodology, reporting at significant stages.

Verification of the model structure and integrity of the data-sets in the model is a related issue. For this reason documentation on models must be complete. Models represent an idealised construction of general system linkages that can then be applied to specific examples of that system. The process of model generalisation involves key assumptions to be made in their development and these need to be specified, together with the sequence followed when running the model. Such documentation is necessary to ensure that integration between different models can occur, and that results can be transferred between studies.

The ideal specification would link the models and results with the proposed metadata repository (see below), in which new data produced by the study would be catalogued.

Developing new information strategies for data

The amount and range of data now available for studies is rapidly increasing, but is dispersed across many different data providers. This means that finding and acquiring the relevant data for a project can be both frustrating and time-consuming. This situation is further compounded by the fact that one data-set may be usefully combined with other data-sets to produce even more data, and data are also available at different geographical scales and time periods. It is also becoming evident that data previously collected for different purposes (e.g. proxy climate indicators) could be useful in climate change studies were it more accessible.

UKCIP could therefore develop and disseminate improved use of metadata. Metadata is the term used to describe the summary information or characteristics of a data-set, or rather the changes that have

occurred during its derivation. In essence for spatial data this is the ‘what, who, when, how and where’ of the data, with emphasis on the last element because of its geographical dimension. By looking at metadata we can decide the ‘fitness for use’ of a particular data-set for a certain project. A metadata repository that catalogued this information would be highly useful in the early stages of all data-intensive projects. It is therefore proposed that such a database be developed for data that may at some time be useful for climate change impacts research.

Other stakeholder engagement and support tools

Stakeholder engagement works at several levels in the Programme: as a way to mobilise resources, to find out what to do and ultimately to deliver actions on the ground. So far fairly rudimentary techniques have been used within the Programme and there is now scope to develop a suite of tools to improve stakeholder engagement. Suggestions for new tools include:

- a) Detailed survey work of the attitudes of key decision-makers towards the impacts and adaptation issue could be undertaken, to find out about levels of understanding of the climate change issue and what exactly deters / motivates action. Surveys have been run on the general public for many years, but not yet on this specialist audience. Their perception of its relation to greenhouse gas reductions would also be helpful. It is also clear there is confusion about the use of terms, and awareness-raising would be helpful about impacts/ mitigation/ mitigating impacts/ impacts of mitigation etc.
- b) Provision could be made to develop visualisation tools more widely within the Programme in association with projects underway. These could be prepared beforehand: to assist studies to explain possible impacts; to better inform stakeholders during consultation stages; and then to visualise results in accessible formats to improve dissemination. In addition decision-support tools could be developed around the new projects underway, i.e. risk and uncertainty in

decision-making and costing climate change impacts.

More detailed work would therefore be useful on the improved communication of information from integrated assessments and their implications. Government departments, government and non-government agencies and land managers have a requirement for more sophisticated tools for policy formulation and implementation. Hence, there is a need to develop more advanced mechanisms for the delivery of climate change advice in the form of computer-based decision support systems. Some stakeholders, such as MAFF, have already begun to develop such systems for current management practices, and these could be extended to include climate change.

The communication of complex spatial information to stakeholders requires the development of user-friendly interfaces to allow quick access to the relevant data and advice. Particularly important is the need for land use decisions to be made in the context of a sustainable environment. This could include decision support in a wide range of subjects such as appropriate crops and stocking, forest species, fertiliser application, and set-aside options, in the context of other changes in the environment such as flooding, water quality and biodiversity.

- c) Consideration could be given to the development of an impacts scenario to elicit stakeholder interests. A combination of high/fast climate change and sensitive sectors would help frame the potential for significant impacts. A low/ slow scenario and low sensitivity would suggest the minimum levels of concern.
- d) The compilation of a systematic information base on significant climatological events in parts of the UK and their impacts would also enhance stakeholder participation by giving some reference events. At present this process is undertaken, partially and anecdotally within studies.

- e) Consideration could be given to facilitate rapid dissemination of existing data-sets and documentary data-sets which are not yet GIS based, particularly on economic and other dimensions, such as the built environment. A considerable amount of information is often potentially available. Ready access to this information would improve the quality of studies by providing better guidance on baseline conditions.

A UK-wide framework

Future impacts work would benefit from a greater understanding of the impacts of global change on the global economy. Initially this would involve identifying the regions which are most likely to experience the most significant changes in production costs through climate change. Such information could then be employed to consider change in the relative competitiveness of the regions and sectors of the UK economy.

Issues emerged within the scoping studies about how climate change will affect competitive relationships internally and with overseas markets.

Concerns were raised at the South West England Conference that the competitive agricultural advantages currently enjoyed in the region could be reduced under climate change. The Wales report highlighted the importance of the impact of climate change on Welsh water resources, given that 60% of water abstracted in Wales is currently exported to England. Lamb production in Wales is expected to be significantly affected by climate change.

The same argument applies to the positioning of the UK within the international marketplace – the UK will experience net gains and net losses as a result of climate change in comparison to other countries.

Contextual national and international frameworks could be developed, which can be used to assess the relative advantages or disadvantages afforded to different areas, and to the UK as a whole, by climate change impacts on some sectors. The national framework will highlight any discrepancies between different sub-UK assessments. This

approach will also help to fill gaps which emerge from the socio-economic scenarios. They avoid the problem of projecting quantitatively from the current situation – which would produce meaningless figures – but do not provide robust coherent advice on future economies.

Frameworks could be developed for the following sectors: agriculture, water resources, and other key economic sectors.

5.2 Research for next stage work on impacts and adaptation

5.2.1 Establishing priorities

Considerable research effort is being expended in improving our understanding of the key impacts of climate change. Nevertheless, there are many outstanding questions to be answered. Important gaps in knowledge have been identified in the Programme from the scoping studies (Chapter 2), through consultation with the UKCIP Science Panel, and by reviewing key studies which preceded the UKCIP (Appendix 2).

Based on these gaps, future research priorities for the partnership approach of UKCIP have

been defined, and they are described in this section. They include a portfolio of studies, ranging from some sectors or regions for which little or no impacts studies have been undertaken, to other sectors where detailed quantitative research is required to address key issues. They are summarised in Figure 5.2a.

UKCIP will seek to secure resources for these studies, which are needed to achieve a national assessment of climate change impacts, through work with stakeholders and other organisations.

This section outlines research priorities for:

- (i) scoping studies for sectors and regions where little or no information is available on climate change impacts;
- (ii) “what if” event-based studies investigating effects of future climate extremes;
- (iii) detailed quantification and case studies for coasts, water resources, agriculture and biodiversity; and
- (iv) integrated assessments developed from the REGIS methodology.

It is recommended that the main priority for research should be on the key vulnerable sectors already identified in (iii), but studies identified in (i) and (ii) will assist in rapidly filling important gaps in knowledge. Studies

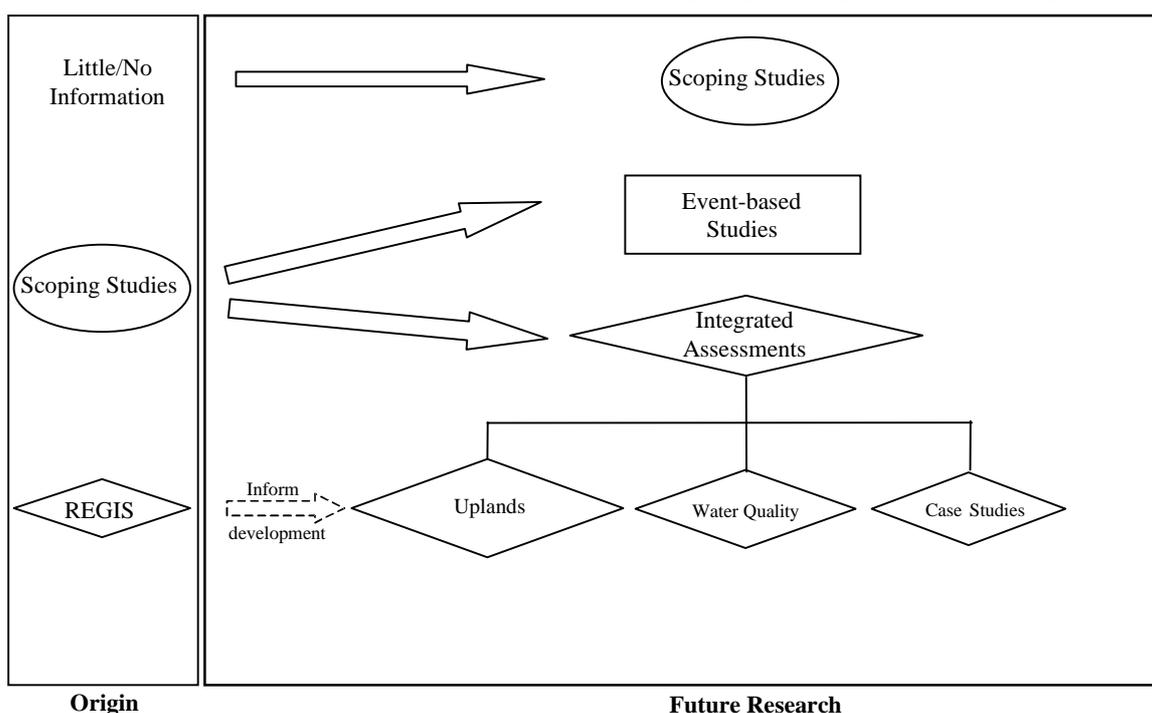


Figure 5.2a: Key issues emerging from completed and ongoing studies (left hand column) have enabled the development of a portfolio of future research priorities (right hand column).

proposed in (iv) would assist in advancing the methodology for integrated assessment and developing the knowledge base for cross-sectoral impacts. Beyond this brief outline, further details on the research agenda are provided in Annex 5.1.

5.2.2 Scoping studies

Review of UKCIP studies to date indicates that some important sectors and regions have not yet assessed their vulnerability to climate change. Scoping studies should be undertaken for these sectors/regions, as a first step in identifying the importance of climate change issues. These studies would be mainly qualitative, and hence comparatively inexpensive to develop. A priority should be to complete the national coverage of sub-UK studies. In addition, we have categorised proposed sectoral studies by their perceived impact on an international or national scale, which may imply a level of priority, at least initially, before detailed results are available.

Sub-UK studies

London

As yet, a scoping study on the impacts of climate change has not been undertaken in London. The city is home to some of the UK's most expensive property and is its centre of commerce. Central London is protected from tidal flooding by the Thames Barrage, designed to provide protection up to the year 2030. Initial studies on the impact of sea-level rise up to 2100 have been initiated by the Environment Agency, but no detailed study on the full spectrum of impacts. Other potential climate change problems include building subsidence and detrimental effects on health.

East Anglia

The Government has recently announced new housing targets for East Anglia, saying that 9,600 new houses should be built in Cambridgeshire, Norfolk and Suffolk each year, to meet the national target of 3.8 million new homes by 2021. However, East Anglia is one of the UK regions most risk from flooding to coastal erosion and flooding. The REGIS study will provide an initial assessment of vulnerability to flooding, but a scoping study

would allow this to be easily extended to all sectors.

Other Areas

As shown in Figure 5.2b, other parts of the UK where scoping studies have not yet been undertaken include:

- Northern Ireland;
- Yorkshire and Humberside;
- North East England;
- Counties in South East England, including Essex, Middlesex, Berkshire, Bedfordshire, Oxfordshire

Sectoral studies - International

Marine environment

Significant changes already appear to be occurring in the marine environment due to shifting ocean currents (e.g. Turrell, 1999). However, as yet very little detailed research has been carried out, despite the importance of these changes for fisheries and biodiversity. Clearly, these issues have an international dimension, with regard to fish stocks and marine conservation, but presently we have only limited knowledge on the processes occurring and their impact on species and populations.

Tourism

This year an estimated 28 million foreign tourists will visit the UK. By the year 2020, visitor numbers are expected to rise to around 56 million. Climate change is expected to benefit the tourism industry in some parts of the UK, with increased numbers of visitors and an extension to the tourist season. There may also be changes in the movement of tourists between the UK and S. Europe. However, there are potential detrimental impacts of increased tourist numbers, since this would put pressure on utilities infrastructure and the natural environment. Relationships between this sector and the weather/climate are subtle and require further research, as such information is essential for designing a proactive adaptation strategy.

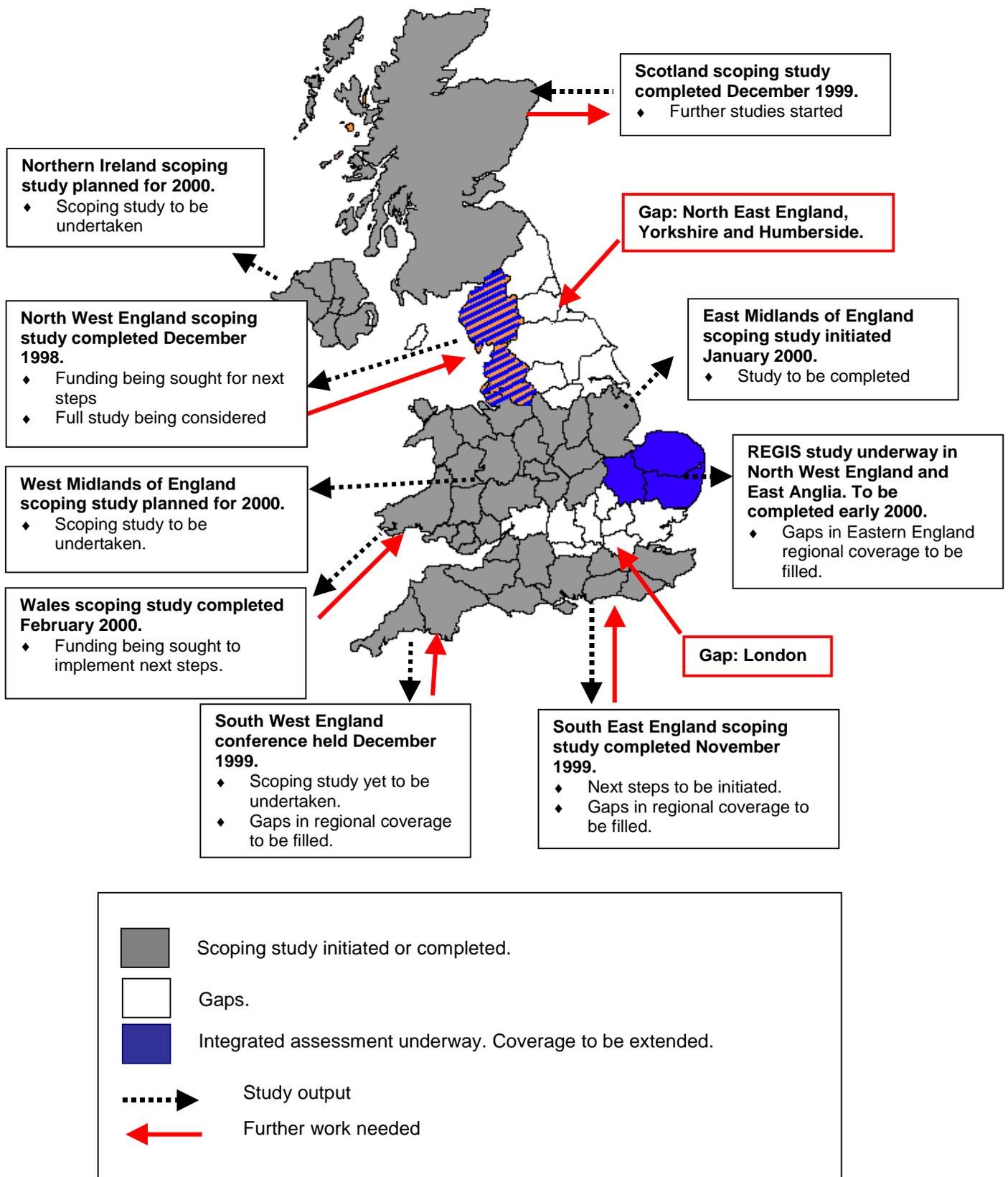


Figure 5.2b: Current status of UKCIP sub-UK studies showing gaps in the national coverage

Sectoral studies - national

Transport and the built environment

A study is at inception on the impacts of climate change on rail infrastructure. However, to date, there have been few comprehensive assessments of the impacts of climate change on transport and the built environment. Infrastructure may be vulnerable due to its location (e.g. ports, railway lines and property close to coasts, underground systems at risk of flooding). More high winds could disrupt all modes of transport and affect property. The construction industry has also been identified as potentially vulnerable to change.

Energy

The direct impacts of climate change on the UK energy sector will be lower than those resulting from market developments or greenhouse gas mitigation policies. However, energy demand for space heating could fall significantly in a warmer climate. Demand for air conditioning could rise. Energy infrastructure often occupies vulnerable coastal sites or is inherently vulnerable to the weather (e.g. overhead transmission lines, wind farms). Power stations have large cooling water requirements and could be affected by water resource or water quality problems. A study to assess the inter-relationships between these factors (including mitigation) would be a valuable first step.

Urban Areas

Urban areas have not yet been systematically covered by UKCIP studies. However, there are likely to be a range of problems specific to these areas, especially with their continued expansion. Cities already modify their local climate. The urban 'heat island' effect will exacerbate temperature rise, and air pollution is likely to increase. Urbanisation increases the risk of flash flooding in catchments and many of the storm water and sewerage systems may have problems coping with increased and more intense rainfall. In addition, rising water tables could lead to problems with underground transport and buildings.

Cultural heritage

Some of the UK's most valued assets are its numerous historical buildings and archaeological remains. They include ancient settlements, fortifications, holy places, prehistoric chambered tombs, stone circles, Roman forts, ruined castles, as well as some less-obvious buildings, such as the first factories of the industrial revolution. Many of these assets are in vulnerable coastal or low-lying areas. A changed climate could damage vulnerable structures and artefacts.

5.2.3 “What if” event-based studies

The summer of 1995 was the hottest and driest on record in many areas, and 1995 was one of the warmest years on record. The economic effects of the weather in 1995 were reported in a study funded by DETR (Palutikof *et al.*, 1997) and effects on agriculture and horticulture were described in a MAFF-funded study (Orson, 1999, MAFF project number CC0322). These studies provided an opportunity to gain some insight into the sensitivity of the UK economy to climate variability and change. The reports suggested that the study results could serve as a point of comparison for impacts from climate change. New studies could be based on specific historical events, for which impacts data are available, or alternatively could examine theoretical weather events suggested by climate models. Three suggestions for such events are made as follows:

- impacts of three successive dry years (e.g. 1995);
- impacts of three successive wet autumns and winters (e.g. 1998); and
- impacts of an extended drought followed by a period of intense rainfall and stormy weather (e.g. 1976).

Each of these scenarios would result in different priorities being assigned to the various sectors, and also variations within sectors. The present climate scenarios may be unable to predict these events with certainty, but emphasis on scenarios of impacts would allow a different perspective to be obtained. Evidence suggests that stakeholders can also often relate to this approach more readily than

to traditional climate scenarios. Studies would also be relatively inexpensive compared to detailed modelling studies.

The TSUNAMI initiative¹, linking research and the insurance industry, is developing projects on risk and extreme events (e.g. flooding, windstorms) which could be used to complement these new studies. Claims databases and risk mapping could be used to ascertain the full economic impact by comparing the "event" with current baseline data.

5.2.4 Detailed modelling studies in key sectors

From gaps and research recommendations identified in UKCIP and other studies, a research agenda has been developed for: coasts; water resources and hydrology; soils, agriculture and biodiversity. Considerable model development will be required for this work. A fuller research agenda is presented in Annex 5.1; here we provide an overview of the agenda and how studies could be framed from it.

The most appropriate format to tackle much of the agenda is as case studies, because such research requires very intensive data and resources (as has been demonstrated by REGIS). It is therefore not feasible to do detailed assessments for the UK as a whole. The focus should therefore be on assessing impacts in detail for specific locations – “hotspots” – where impacts will be most important.

Three steps are suggested:

- 1) analyse completed and ongoing research to identify most important impacts;
- 2) identify the critical hotspots - the important locations that are known to be at risk; and
- 3) undertake case studies at these selected hotspots.

The hotspots will be the places where climate change could lead to the greatest loss, according to predetermined criteria covering

impacts on: economic sectors, strategic resources damaged (food production, water) and valued landscapes and biodiversity. They should also be places for which good data-sets are available.

Coasts

Predictions of future coastal changes are dominated by uncertainty, which hinders adaptation. Even the regional and national picture requires clarification in some topics, building on current research (sponsored by MAFF² and the EA³). Hence, a study processing newly-available tide gauge data would allow the local impacts of sea-level rise to be determined more accurately. There is also a pressing need for further studies quantifying changes in the magnitude of storm surges, wave heights and tidal dynamics and their different spatial impacts. However, the most detailed new research needs to be concentrated on holistic case studies of vulnerable areas, building on research that has clarified the present-day situation. Examples include The Solent (with Chichester Harbour etc.), Morecambe Bay and the North Norfolk Coast. These studies need to integrate both offshore and onshore environments, necessitating more precise information on offshore bathymetry and sediment dynamics. Remote sensing data can provide this extra detail. Evaluation of the feasibility of intervention policies, such as managed retreat, at various different sites is needed. If sea-level rise accelerates and the wave regime is modified, will the best sites to produce the required salt marsh around the UK coastline remain as at present? Another study needs to address the threat of saline intrusion into valuable coastal soils.

Water resources and hydrology

Despite the considerable amount of research that has been undertaken in the water sector (e.g. see Section 3.5.2 and Appendix 2), quantification of impacts requires more detailed catchment-based case studies in the future. To facilitate this, research on better

¹ See TSUNAMI web site at <http://www.nbs.ac.uk/public/tsunami/index.html>

² Further details at web address <http://www.maff.gov.uk/research/default.htm>

³ Further details at web address http://www.environment-agency.gov.uk/envinfo/r_and_d/

downscaling techniques to convert GCM/RCM data into local catchment data is essential to improve accuracy of water resource forecasts. Further climatological research is also needed to reduce the uncertainty regarding the future risk of droughts, particularly the occurrence of back-to-back drought years. In hydrology, studies are needed to develop more accurate catchment models, driven by hourly/daily climate scenario data, which would allow derivation of improved magnitude-frequency relationships for floods and low flows, together with derivation of better information on water quality impacts. These projects could also aim to distinguish the effects of climate change from land-use change in catchments. Similarly, there is a pressing need for a new study evaluating changing seasonal variations of groundwater reserves. Water demand research requires new studies to incorporate improved socio-economic models for the future and likely impacts from changing regulation. This research should also be conducted in the context of whether the current institutional structures could respond to future extreme events. DETR are currently commissioning further work on demand modelling and adaptation responses. The Environment Agency and UKWIR are also conducting research into the impacts of climate change on water quality.

Soils, agriculture and biodiversity

Despite their significance for agriculture and terrestrial ecosystems, soils have been an under-researched topic. A new study could investigate the response of soil micro-organisms to a changing climate, as this has major implications for rates of decomposition of organic matter and the role of soils in the carbon cycle. Vegetation changes can also lead to differences in soil formation, but how fast is this rate of change, and what are the feedback mechanisms operating? Similarly, with biodiversity, a study to examine rates of habitat and species migration under climate change is desirable (the MONARCH study will only provide this for certain key species at fixed intervals: 2020, 2050, 2080). In agriculture, further research needs to be funded on effects of changed seasonal climate variables, as timing of agricultural operations is often critical. Linked to this is the need for new studies on agricultural water use and

water quality changes. This would extend the results from REGIS to look at different catchments (e.g. chalk downland) and seasonal variations.

There is a good case for integrating agriculture and biodiversity research in the same framework to facilitate a co-ordinated response. A recommended cross-sectoral case study is the potential effects of new crops (grown under a changed climate) on soil nutrient cycling and water use. Research also needs to be linked to improved monitoring networks.

5.2.5 Integrated assessments

The REGIS study has been developing an initial methodology for integrated assessment and further studies based on this research would be fruitful to test the methods and make them more robust. Hence, although the results from REGIS may not be directly applicable to other parts of the UK, the methods can be built on and extended. For instance, the impact of adaptation measures could be incorporated more directly in the methods. The fact that REGIS has researched two distinct areas of the UK has considerably assisted in developing a transferable methodology (and in some cases, results too), and is recommended for future studies. Two further studies are proposed for further discussion:

- extension of the REGIS methodology to vulnerable upland areas, such as in Scotland and Wales, including additional variables such as forestry, soil erosion and farm animal stocking;
- an integrated assessment of climate change impacts on water quality, including within-sector adaptation measures and looking at the effects of extreme events.

5.3 Conclusions

Considerable progress in assessing vulnerability to climate change has been made in UKCIP studies to date. However, with respect to core products used in studies (data, models, scenarios) there is a need to develop improved methods as the programme matures.

There is also a requirement to develop more innovative tools to engage stakeholders.

Although the present studies have collated an impressive array of results, it is clear that the knowledge-base on impacts assessment and adaptation strategies is in need of further improvement in a number of areas. A UK-wide framework in which results from different areas could be integrated would be a useful step. Suggested priorities for research include a portfolio of studies (Fig. 5.3a), ranging from scoping studies for sectors and areas where little information is currently available, to detailed modelling studies within the key sectors. This should also facilitate quantitative integrated assessments and case studies at key locations. New research should be specified so that it builds on existing studies, and takes advantage of new

developments in data and scenarios (both climate and non-climate).

5.4 References

Palutikof, J.P., Subak, S. and Agnew, M.D. (1997) *Economic Impacts of the Hot Summer and Unusually Warm Year of 1995*. University of East Anglia, Norwich, 178pp.

Orson, J.H. (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, Oxon. 172pp.

Turrell, W.R. (1999). *Scottish Ocean Climate Status Report 1998*. Fisheries Research Services Report, No. 9/99. Marine Laboratory, Aberdeen.

Annex 5.1: Further details on the research agenda

A5.1.1 Scoping studies

London

Currently, the major flooding threat to central London is from storm surges, when weather conditions exaggerate tidal peaks. With climate change, the Thames Barrier (designed to protect the capital until 2030) is likely to need to be closed more frequently than at present and the risk of the barrier being overtopped is likely to increase.

Clay soil predominates in many parts of London. It is prone to drying out and cracking during periods of extended drought. Under these conditions, subsidence of properties can result. Indeed, after the drought of 1976, rates of insurance claims for subsidence in London were among the highest in the country.

Recently, high tides have forced part of the London Underground system to close. With the water table rising, the likelihood is that more disruptions to the system will occur, unless adaptive measures can be taken. The implications for transport in the capital could be severe.

The impacts of climate change on the capital's health could also be important: heat stress, particularly among the elderly and the poor, is likely to increase. Climate change will also exacerbate London's air quality problems.

East Anglia

East Anglia is vulnerable to flooding from sea level rise, yet there are plans to build large numbers of new homes in the region over the next 15 years. Clearly, if the intention is to expand the housing capacity of the region so vigorously, a scoping study of climate change impacts should be undertaken.

East Anglia is one of the regions being studied in REGIS, but this study examines the integrated impacts of climate change on only four sectors: agriculture, hydrology, biodiversity, and coastal areas. Impacts on the built environment are not directly addressed,

except for an assessment of likely changes in flood risk.

Marine environment

Both the South West England and Scotland scoping studies highlighted the marine environment as a topic of major concern and high uncertainty. These parts of the UK have a significant fishing industry, which is especially vulnerable to climate change, as fish are very susceptible to changes in salinity and temperature. New studies to derive more information on the sensitivity of the UK's marine zone would be highly useful in this context. Of particular concern is the potential changing pattern of ocean currents, as this can alter the amount of food available to mature fish and disrupt the dispersal patterns of larval fish to the main fishing areas. The location of colder arctic water compared to warmer, saltier water from the tropics is a key factor in fish distribution. Turrell (1999) has already reported preliminary evidence suggesting that ocean currents are changing, including an increase in salinity, which has been linked to salmon survival at sea. Research is needed to ascertain whether this is an initial response to climate change and to establish the role of natural variability (e.g. the North Atlantic Oscillation) in ocean changes so that the climate signal can be distinguished.

Studies in the marine environment need to be initiated at the national (UK) or international (EU) level because they extend beyond regional boundaries. With regard to fishing, results need to be input into the EU quota system to help maintain a long-term sustainable fish stock. A review of the impacts on key species would be a significant first step in this process, but this also requires improved fish population models. Research is also needed into the impact of new species on ecosystems and the EU-led designation of marine nature reserves. As with the terrestrial environment, this requires the development of improved monitoring networks to determine more accurately the changes that are occurring.

Tourism

Climate change is widely expected to boost the tourism industry in parts of the UK, with increased numbers of visitors and an extension to the tourist season. The UK tourist industry could benefit significantly, possibly at the cost of Southern European tourist destinations, which may become too hot under climate change. Increased tourist numbers would, however, increase pressure on utilities infrastructure and the natural environment. Existing transport infrastructure in the South West, for instance, is already stretched during the peak tourist season.

To date, little research has been undertaken into the observed and perceived effects of climate on tourism.

Transport and the built environment

The aspects of transport and the built environment likely to be most affected by climate change include:

- infrastructure (property, roads, rail, underground systems and sea-ports) close to coasts and estuaries, which will be more prone to flooding as a result of sea level rise;
- damage to infrastructure caused by high winds and heavier rainfall;
- potential benefits from less icing in winter;
- disruption of all modes of transport due to increased frequency of strong winds;
- potential damage to transport infrastructure (notably road and rail materials) due to higher temperatures;
- the construction industry may be required to adapt to new designs, materials and working practices.

In addition, transport is affected by climate-induced changes in other sectors, most notably tourism. Increased storminess could have important implications for transport to remote areas, such as the Scottish islands.

Energy

Little research into the impacts of climate change on the energy sector has been undertaken. Climate change could reduce

energy demand for space heating by about 5% below the level that it would otherwise have been by the 2050s, but could increase the demand for air conditioning.

The scoping study should address the following potential climate change impacts:

- changes to domestic and business energy requirements due to warmer winters (less heating) and warmer summers (more air conditioning) and effects on peak demand;
- impacts of riverine and estuarine flooding and sea-level rise on energy infrastructure located close to rivers and coasts;
- impacts of climate change on renewable energy sources such as biomass, hydro-electricity and wind;
- knock-on effects that impacts on water resources will have on power station cooling water requirements;
- effects of tightened effluent discharge standards on management of wastes from power stations;
- storm damage affecting offshore oil/gas exploration and production, overhead lines and renewable energy systems.

The scoping study would benefit from the RCM outputs (which will form the basis of the new UKCIP2001 climate scenarios) since these will provide a better indication of the regional variability of the wide range of climate variables that may influence this sector.

Urban areas

A full assessment of the vulnerability of urban areas remains to be achieved, although sub-UK scoping studies have identified some key issues. This assessment would provide a valuable basis on which to plan for the future in terms of buildings and infrastructure. Temperature, wind and rainfall are modified over cities and these may cause important local variations in the predicted impacts of climate change. Air pollution is already a major concern in many areas, and this could potentially increase in the future with consequences for public health. Storm water and sewer systems may need adapting to cope with more intense rainfall episodes, which can

present a severe flooding problem for urban areas because of the large proportion of impermeable surface. In addition, rising water tables could cause structural and underground transport problems, as noted for Liverpool buildings. It would be highly beneficial to integrate this study with the proposed scoping study for London.

Cultural heritage

The UK's many historical buildings and archaeological remains draw thousands of visitors each year. Scheduled Ancient Monuments and Listed Buildings are protected under law. In early 1998, there were about 6,800 scheduled monuments in Scotland and at the end of 1994 there were 444,508 entries on the lists of historic buildings in England. The UK is also rich in its stock of ancient churches, which if they are in ecclesiastical use, can not be Scheduled Ancient Monuments.

The potential threats posed to these historical buildings and historical remains by climate change are many and various, including:

- buildings and archaeological remains located on coastal areas at risk of erosion (e.g. Tintagel Castle, Cornwall; Belle Tout at Beachy Head; Dinas Dinlle, Wales);
- buildings in flood-prone areas (e.g. many Norman churches in East Anglia);
- stress on archaeological sites and loss of organic artefacts preserved by waterlogging, due to lowered water tables in summer droughts;
- some archaeologically-rich island sites, such as Iona, are vulnerable to increased coastal erosion;
- stress caused to structures as a result of changed climate and particularly climate extremes (e.g. storm damage, droughts causing cracking of soils and thus subsidence); and
- effects on fabrics, paintings and furniture of changed temperature, humidity and UV-B radiation.

So far, insufficient research has been undertaken on the potential effects of climate change on the cultural heritage sector.

A5.1.2 Further details: “What if” event-based studies

Impacts of three successive dry years

At present there is no compelling evidence from the UKCIP climate scenarios that successive dry years will become more common in the future. However, changes to precipitation patterns under climate change are difficult to model using GCMs, largely because GCMs do not include the topographic effects that dominate local precipitation patterns. Furthermore, the impacts of back-to-back droughts were identified as being of key concern in the sub-UK scoping studies. Clearly, successive years of drought have enormous implications for the management of water resources and for agriculture and biodiversity, as well as affecting tourism, infrastructure, industry and the built environment.

Impacts of three successive wet autumns and winters

The UKCIP98 scenarios for 2050 indicate that precipitation in autumn and winter is expected to increase by up to 17%. Scoping studies identified key impacts from wetter weather, including: increased soil erosion; increased risk of pollution of water courses; risks of river flooding; and increased damp in housing stock. The last point was particularly stressed in Scotland, where damp problems in housing is already a major issue and autumn precipitation is expected to increase by up to 17% by 2050). The impacts of successive years of heavy rainfall might be exacerbated in the agricultural sector, if summer rainfall shortages lead to more crops being planted and grown during autumn and winter. Summer crops would face increased harvesting problems.

Impacts of an extended drought followed by a period of intense rainfall and stormy weather

The scoping studies highlighted the significant impacts that could occur if a period of drought was followed by an intense rainfall event – a pattern of weather that is predicted to become more common in the future. During periods of drought, concentrations of sediments allow the accumulation of pollutants on the land. The

first flush of run-off into receiving waters may therefore contain unusually high concentrations of pollutants. Soil erosion caused by wind and rain after an extended drought could also be significant.

A5.1.3 Development of a case study approach: further details

Certain places in the UK, valued either for their economic worth or for their importance as a natural feature, are particularly vulnerable to climate change impacts by virtue of their location. These “hotspots” should be the focus of detailed integrated assessment in Case Studies. From the Scoping Studies, some candidates “hotspots” have already been identified.

- **Chichester Harbour:** The harbour is an Area of Outstanding Natural Beauty, comprising 11 square miles of water and 11 square miles of land. It sustains multi-million pound yachting and tourism industries and is designated as a SSSI, SPA, Ramsar site and a potential SAC, because of its ecological importance. East Head is an important natural feature of the harbour, and protects properties, but is under threat from coastal erosion, sea level rise and storms.
- **Morecambe Bay:** The bay is vulnerable to sea level rise. Major floods have occurred three times in the last thirty years. The combination of high tides and strong westerly and south westerly winds, resulting in increasing wave heights and tidal surges, are the main threat in this location. Existing sea defences will be increasingly challenged over the next 50 to 80 years. The most endangered butterfly in the UK, the High Brown Fritillary, occurs around Morecambe Bay (one of only three populations nationally).
- **Chalk Streams:** Candidate sites include the Kennet catchment, which has its source in the chalk Marlborough Downs. In Hampshire, the Test and Itchen catchments are also noted for their chalk

streams. Sections of each of these rivers are designated as SSSIs. The South East England scoping study targeted water quality in the region’s valued chalk streams as being of key concern under climate change.

A5.1.4 Coasts; water resources and hydrology; soils, agriculture and biodiversity

Coasts

The sub-UK and regional scoping studies have clearly identified the coastal zone as a major topic for future research, with the most vulnerable areas being broadly identified by stakeholders and expert judgement. Present-day stability of the coastal zone is often the result of a delicate balance between many competing natural and human-influenced processes, and this dynamic equilibrium could be easily disturbed by future change.

However, even though awareness of climate change impacts is highest amongst coastal stakeholders, it is not at present directly incorporated into the planning process. Shoreline Management Plans (SMPs) represent a significant step forward in the collation and analysis of coastal data. Generally, present allowances for sea level rise are taken into account, although there are few specific references to adaptation based on climate change. This is probably because considerations are dominated by the current risk. Future levels of risk will increase under climate change, and it is considered most likely that areas similar to those currently at risk will be affected. Hence, as stated in the recent SMP for the Humber Estuary, one of the most advanced planning documents to-date, “in the absence of a clear recommendation for the allowance that should be made for climate variability, none has been included in this plan” (Environment Agency, 2000, p.22). MAFF are currently reviewing the existing SMPs in England and Wales, and guidance for second-round SMPs will include the need to consider potential coastal evolution over the next 50-100 years, which should stimulate significant progress. Other uncertainties (e.g. changes in storm frequency and intensity) are

considered to be not yet quantifiable from the current climate scenarios and their inclusion in future SMPs will require further research and guidance.

Other coastal policy tools that do not currently make provision for climate change include Biodiversity Action Plans (BAPs). The designation of conservation sites is a static concept, despite the potential for a changing coastline. Local conflicts, as exemplified by the 'Brancaster question' ("should we conserve coastal grazing marsh or salt-marsh at this site?"), already hint at the nature of the planning problems that will arise. The development of a new suite of Coastal Habitat Management Plans (CHaMPs), however, will include a remit to provide an indication of likely shoreline changes in the next 50 years.

By considering the lack of knowledge on key variables in the coastal zone, the need for further research becomes very evident. For instance, the influence of climate change on: height and frequency of storm surges; wind direction and wave regime; estuary morphology; sediment supply; and the pattern of erosion and deposition; are all subject to a high level of uncertainty in both space and time. Furthermore, as each of these factors combine and interact, this uncertainty is propagated. Even sea-level rise, for which global estimates are available from the climate scenarios, has complex local variations due to the varying pattern of subsidence/uplift from isostatic compensation. For example, the South East England scoping study reports tide gauge data indicating areas of The Solent are likely to experience relative sea level rises equivalent to 10mm yr^{-1} . This may be an instrumentation error but the sparsity of good data means that many other anomalies exist in the prevailing model of spatial variability, suggesting a revision of the model may be required. Evidence is also conflicting over whether the predicted acceleration in sea-level rise has already begun, and this requires further monitoring and modelling. Furthermore, the influence of sea-level rise on the return periods of extreme water levels needs to be clarified, as these are the design limits for coastal defence structures. A MAFF-funded project at the Proudman Oceanographic Laboratory is addressing this issue, but more work using the extra precision

offered by the UKCIP 2001 climate scenarios is needed to elaborate upon this.

Considerable uncertainty exists regarding the present-day coastal environment. However, a number of studies initiated by MAFF and the Environment Agency are currently tackling this issue. These should provide a sound platform on which to model potential future changes. The need for further information applies particularly to the complex offshore environment, which is often neglected in considering coastal change, despite its profound influence on the onshore zone. Changes in bathymetry can increase wave energy, fundamentally altering the balance and pattern of erosion and accretion along the coast. Bathymetric profiles can be altered by changes in the wave climate as well as long-term increases in water levels, and some evidence already exists for a recent increase in wave heights. Offshore sandbanks, found along many areas of the coastline, are in a continual flux due to changing tidal streams, with an apparent cyclical pattern of movement on a decadal time scale. Climate change, by altering the controlling variables, may induce a breakdown of the prevailing sediment dynamics. This is of importance because many of these sandbanks considerably reduce wave energy reaching the shore, in all but the highest tides. Future dredging of the offshore environment for marine aggregates may no longer be sustainable in this context. Offshore material is often used for local beach nourishment but this use also requires further research to ascertain its viability in the long-term, and the depletion of some beaches may be inevitable. Sand and shingle spits (e.g. Hurst Spit in The Solent), which protect many harbours, are also especially vulnerable to change. The pattern of erosion and accretion is liable to be modified around the coastline, with potential shifts in the sediment type (i.e. mud, silt, sand, gravel). Sediment supply also has a major impact on ecosystems, and a further hazard may be remobilisation or redirection of toxic substances in estuaries.

Further research is required on many other related aspects of the coastal zone. One of these is the feasibility of managed retreat on appropriate sections of the UK coastline: for instance, will salt-marsh rather than mud flats form, or will the salt-marsh development be

able to adapt to the increased rate of sea level rise, or changes in wave regime? Previously, extensive research and pilot schemes in East Anglia and South West England have established that there is little problem in re-establishing mud flats and salt-marsh on previously protected land, with the land level relative to the sea being critical for salt-marsh. However, often the optimal site in natural terms is not the most suitable politically. Once the land is inundated and becomes saline, there is no possibility of quick reversal.

The vulnerability of individual ports to changing climate and offshore parameters also needs clarifying; in some cases, long-term historical data are available that could assist in this. In addition the potential impacts of saline intrusion of groundwater needs further research to establish the spatial pattern of vulnerability and the likely magnitude of change. These topics need to be incorporated in a more holistic approach to coastal issues, with climate change factored in to a dynamic physical and human environment.

Coastal studies need to be focused on sediment cell units to establish the full dimensions of change. Each cell represents an area where the cyclical coastal processes can be considered internal to that unit and have minimal connection with those outside. MAFF's strategy for coastal defence is built around these cells. From the research recommendations made in the regional studies, we can already link these to vulnerable areas (e.g. The Solent, Morecambe Bay, Bristol Channel).

A significant incentive for further research on the coastline is that new and more accurate data-sets are becoming available, (see Appendix 1) which should assist in quantifying the magnitude of impacts more precisely than before. These data include high-resolution elevation data-sets (Light Detection and Ranging - LIDAR and Synthetic Aperture Radar - SAR), better bathymetric data (wide swathe sonar), and data from tide gauges which have been calibrated to nearby onshore global positioning system (GPS) stations. Remote sensing also allows coastal dynamics, such as sediment transport, to be monitored at a much better resolution than before. GPS will allow the local land movement and sea-level

rise components to be decoupled so the two components of sea-level changes can be separated.

Water resources and hydrology

As outlined in Section 3.5.2 and Appendix 2, the water sector has already conducted considerable research into the impacts of climate change, but a large degree of uncertainty still remains. In addition, with the exception of hydrological studies, much of the research has not been in the public domain. UKCIP has a role in promoting an independent national research agenda and communicating the results to stakeholders. The principle need is for integrated catchment-based water models incorporating such factors as changed precipitation patterns, demand management, land-use, agricultural and urban run-off. Initial research is currently being conducted on large catchments (i.e. the Severn and the Trent) by the Institute of Hydrology. The availability of more precise spatial and temporal climate information from the UKCIP2001 climate scenarios should provide a major spur for action in this sector. Some of the issues that need to be addressed are highlighted below.

One of the major research issues is deriving the necessary climatological data from GCMs or RCMs to run hydrological models. As hydrological models are based on catchments, there is a pressing need to develop "intelligent" downscaling methods that can produce data at this level. Some work has already taken place on this topic, such as the EU-funded projects POPSICLE and WRINCLE, which assess methods for downscaling precipitation data. Linked to better catchment-based models, is the need for better modelling of groundwater aquifer recharge. Currently, the best figures available refer to percentage change in annual recharge, but this is not always suitable for resource management. As outlined in the South East England scoping study, there is a need for complete regional assessments of groundwater supply and better information on its temporal vulnerability. Further research is also required on the probability of specific multiple events from the climate scenarios, notably back-to-back droughts and their impacts. Water quality in addition to water yield needs to be built into assessments. The threat to lower river abstraction points from

salinisation is one issue that needs to be more precisely defined.

On the demand side, it would be extremely useful to commission an independent review of likely future demand and the implications that climate change will have for this, including factors such as increased usage for gardens and irrigation. MAFF have developed some initial work on irrigation demand. This needs to be linked to better regional socio-economic scenarios. Key findings from other projects (Appendix 2) indicate that institutional frameworks for handling drought are poorly organised and exclude many stakeholders, a point which deserves further analysis.

More detailed spatial and temporal data are also required for evaluating riverine flooding impacts. Again, this requires information to be derived at the catchment level and further data on extreme events, so that precipitation duration and intensity can be related to local drainage basin conditions (i.e. size, land use, topography and geology).

For both flooding and water resources, comparative studies on catchments which have similar precipitation inputs but differ in other variables, could be used to separate climate change effects from catchment changes that may occur due to changing land use (e.g. vegetation changes, urbanisation). Research into the changing pattern of evapotranspiration, snowmelt and summer convective storms would also be extremely useful, especially as more information on these variables will become available in the UKCIP2001 climate scenarios.

More precise spatial and temporal modelling will allow further investigation of potential future non-linearities in the hydrological system, as current flood defence design is based on historical evidence which climate change may alter significantly. Even the present data contain uncertainty, however estimates of the 100 year flood discharge are in some cases believed to be up to 20% in error (equivalent to 0.2m - 0.5m in water level). Hence, any hydrological modelling needs to be able to provide a quantitative assessment of uncertainty along with the model results. Further developments in risk-based approaches should be applied to the fluvial environment.

In this context, a very useful link would be to further develop the Flood Risks project developed by the TSUNAMI initiative (which is sponsored by the insurance industry).

Soils, agriculture and biodiversity

The effects of climate change on agricultural soils deserve more research, because soil underpins terrestrial ecosystems and agricultural productivity. Furthermore, soil is an important source and sink of greenhouse gases.

Topics of concern include:

- nutrient cycling and its effects on fertiliser use and timing of application;
- changes in soil workability through both drought and heavy rainfall; and
- effects on soil erosion of increased rainfall intensity, changing irrigation use, timing of crop production and type of crops sown.

Increasing temperatures and changing precipitation patterns will affect soil micro-organisms, processes and properties (e.g. content of organic matter and soil water balance). Soil organic matter levels are determined by the balance between carbon inputs to soils and the rate of loss of carbon due to decomposition. Changes in the soil water balance brought about by climate change have important implications for agriculture and land use. Increased soil erosion is expected due to more intense rainfall events, especially when they are associated with strong winds. Increasing atmospheric carbon dioxide concentrations will affect plant growth and will have consequent effects on organic matter, decomposition rates and nutrient balances.

Clearly, the potential impacts of climate change on soils are varied and many of the impacts will be strongly regional in character. However, at present, many of the impacts are not well quantified. The application of the new UKCIP2001 climate scenarios, which will provide more detailed spatial data, would allow improved assessment of regional impacts on soils. A useful study output would be a map showing the likely changes in soil types in the future as a result of climate change.

One specific soil type for which additional research is required is peat soils. They play an important role in carbon storage: it is estimated that the upland peat bogs in the UK contain 200 times as much carbon as all UK vegetation. Soil organic matter formation and peat formation is favoured by cool wet climates and waterlogged soils. Decomposition of peat soils increases with temperature, provided, however, that the soils retain sufficient moisture for the decomposer organisms to function. Production of plant biomass also increases with temperature and length of growing season, given adequate water and nutrients. The net effect of these factors under climate change on the valuable peat soil resource is currently uncertain.

The effects of increased rainfall on livestock farming and timing of livestock production also requires further consideration. Similarly, more information is required on the effects of climate change on pests and diseases of agricultural crops, and the changes required in timing and intensity of spraying to adapt to this change. The introduction of new crops may also lead to different patterns of nutrient cycling with potential detrimental effects on soils.

With regard to biodiversity, consideration of the speed of habitat and species migration under climate change and the rate of colonisation need to be addressed, taking into account the likely availability of suitable habitats. Development of monitoring systems capable of detecting responses of BAP priority habitats and species would be very useful, particularly for the most vulnerable habitats, such as montane and raised bog.

Across both sectors, there is a need to link biodiversity impact studies to agricultural studies, to strengthen the protection of designated sites and to ensure that appropriate measures are in place to support biodiversity in the countryside (such as agri-environmental schemes). In agriculture, there is a need for reconciliation of adaptation measures and mitigation measures to reduce CO₂ emissions. Improved information provision to farmers on efficient use of water and of different irrigation techniques is also required, with one possible line of research being decision support tools (see Section 5.1.2).

A5.1.5 Integrated assessments: further details

Cross-sectoral assessment for uplands: examples from Scotland and Wales

Extension of the REGIS study methodology would be particularly suitable for Scotland and Wales. Scoping studies have identified these areas as having distinct vulnerabilities from other UK areas (although the North West England uplands have some common issues), and the Welsh study highlighted the need for a next-phase integrated assessment in the uplands. A detailed cross-sectoral assessment would assist in identifying unique local issues and also allow improvements to the general methodology. Vulnerable upland areas include the Cairngorms, the Brecon Beacons and Snowdonia.

Data and resource constraints imply that attempting to cover large areas would be prohibitive, therefore it is proposed to concentrate on vulnerable areas with good data-sets already available. New research advances in other sectors, notably water resources, should be input into the integrated assessment, allowing more spatially-detailed work than in REGIS to be developed. This suggests that the most appropriate scale at which to develop models is at catchment scale. Example catchments for which considerable data already exists are the Ythan and Dee (North East Scotland) and the upland site of Plynlimon (mid-Wales). Some existing work has already been done in these areas on issues such as nitrogen deposition and acid rain, which would provide useful baseline information.

The proposed study could also examine additional variables to those presently in the REGIS project, without significant methodological change. This includes important factors such as forestry, soil erosion, peat soils and changing patterns of farm animal stocking (REGIS mainly deals with crops). It would also be necessary to include the policy dimension, and strategies for adaptation, by integrating the scientific work with changes resulting from existing and proposed agri-environmental schemes (see Section 4.3).

Water quality study in South East and South West England

At present, there is a lack of detailed research information concerning the effects of climate change on river water quality beyond the current EA/UKWIR study into this topic. Using the methodology developed in the REGIS project, an integrated assessment of impacts on river water quality, including within-sector adaptation measures, could be undertaken. In common with REGIS, such a study should be undertaken in two locations, allowing comparison of the results of the different studies.

As outlined above, the data-intensive nature of such a project means that it should be undertaken on a catchment or sub-catchment basis.

The study should assess the interrelation of the climate change impacts outlined below for their effects on chemical and biological water quality:

- Interaction between rainfall, evaporation and temperature and the resultant effects on runoff and recharge;
- Changes to river flows: in the South East and South West, river flows are likely to increase in winter and decrease in the summer;
- Lower summer flows will result in reduced dilution of effluent from sewage and waste water treatment works;
- Possible increases in the efficiency of sewage treatment works at higher temperatures, with treated effluent reducing biochemical oxygen demand and improving water quality;
- Demand management measures (such as recycling) will mean that return flows from waste water and sewage treatment works are lower in summer months;
- Agricultural run-off will change as new crops are grown and soil microbial activity is affected, with resultant effects on nutrient cycling;
- Increased soil erosion as a result of increased rainfall totals and heavier rainfall events will increase turbidity, solutes and sediment-associated pollutants (including nitrogen, phosphorus and *Cryptosporidium*);

- Urban runoff: existing storm water systems could overflow during the intense rainfall events which are predicted to occur more often under climate change;
- Changed plant species, with different rainfall interception and evaporation characteristics, will change the dynamics of the processes by which rainfall is converted to runoff; and
- Higher temperatures in nutrient-rich waters will tend to encourage weed and algal growth and increase the likelihood of eutrophication.

Together such impacts may result in serious deterioration in chemical and biological water quality.

The research should include examination of the effects of particular extreme events, which are predicted to occur more often under climate change, such as the impacts of periods of drought followed by intense rainfall, as well as the impacts of back-to-back droughts. Under such conditions, the first flush of runoff may contain unusually high concentrations of pollutants.

Such a study should be designed to inform those with responsibility for maintaining water quality. Since reduced river flows in summer will mean there is less water available for dilution of effluent discharges from sewage and waste water treatment works, higher effluent standards will need to be achieved if water quality is to be preserved. Thus, the information generated in a study of this type will be relevant both to the Environment Agency (who license such discharges) and to the water company responsible for the effluent.

The study should also investigate adaptation strategies, including the effects of higher effluent discharge standards.

The study could focus on two distinct types of water catchment. Suggested examples (both SSSIs) are:

- The River Camel, in Cornwall, which has its source in the granite uplands of Bodmin Moor and ends in the Camel Estuary on the north Cornwall coast. The sediments in the estuary may have

accumulated metalliferous mine and industrial wastes, which could affect fisheries (larvae) and bathing water quality close to the estuary.

- The Test catchment in Hampshire is noted for its chalk streams. Sections of the river are designated as SSSI.

A5.1.6 References

Environment Agency (2000). Planning for the Rising Tides. The Humber Estuary: Options Consultation Document.

Turrell, W.R. (1999). *Scottish Ocean Climate Status Report 1998*. Fisheries Research Services Report, No 9/99. Marine Laboratory, Aberdeen.

Appendix 1

Core data-sets being used in UKCIP studies and example data-sets from new technology

Iain Brown

AI.1 Core data-sets used in UKCIP studies

The following data-sets have been identified as central to impacts assessment in the present studies, although many others are being utilised. Data are manipulated in the UKCIP GIS¹, although copyright remains with the original providers.

Soils

Information on soils is core data for climate change impacts research because soils are a fundamental consideration in all biodiversity and agricultural studies. Due to various national initiatives, and the importance of soils for agriculture, a large amount of detailed soils information exists for the UK. This includes not only the soil types present for a particular area, but also detailed sampling of their properties, such as available water capacity (AWC), pH, percolation rate and thickness of the various horizons. Some of the variables, particularly AWC, are important as limiting factors on plant growth, hence their use in the SPECIES biodiversity model being used in the REGIS and MONARCH projects. For the MONARCH project attempts are being made to integrate soils data from organisations in England and Wales (Soil Survey and Land Research Centre, SSLRC), Scotland (Macaulay Land Use Research Institute, MLURI), Northern Ireland (Department of Agriculture, Northern Ireland, DANI) and the Republic of Ireland. However, this is not

straightforward because the respective organisations have used different approaches in collecting the data.

Land cover and land use

Information on the current locations of types of land cover is essential to determine the future spatial pattern of landscape change. For this purpose, the Land Cover Map of Great Britain produced by the Institute of Terrestrial Ecology (ITE) is proving very useful in providing a uniform assessment of the different land use and vegetation types across the country. The data are classified into 26 categories (e.g. deciduous woodland, open shrub heath, urban, tilled land, urban areas) and is being used at two grid cell scales: 1km and 25m. In addition to data values showing the dominant land class per grid cell, the 1km data-set is also available as % values for each land class per 1km cell. The latter data are useful to ascertain more precise estimates of the proportion of the land covered by different classes.

The 1km data-set is useful for analysing large areas across the whole of the UK, whereas the high-resolution 25m data excel for studying site-specific impacts in vulnerable areas, notably the coastal zone. For example, the exact distribution of areas of salt marsh can not be obtained from the 1km data, because in a 1km grid square other land cover types may predominate, but at the 25m scale much more precise estimates can be obtained.

The ITE land cover map has been derived from satellite data (LandSat) and classified by mapping the spectral band characteristics for each pixel to a target class based on ground truth information. Similarly, other initiatives

¹ Some of these data are also available in the DETR's Countryside Information System, a low-cost interface to a range of data-sets geo-referenced to the National Grid, although without the full functionality of a GIS. See <http://www.cis-web.org.uk> for more details.

have derived different classifications from the satellite data. For example, in the REGIS project, the ITE map is being compared with an Environment Agency classification emphasising land *use* (e.g. residential, commercial, recreational, agriculture). Both classifications appear to have a role in assessing the impacts on the natural (land cover) and the human (land use) environment respectively. The ITE Land Cover Map has been converted to the CORINE. Land Cover standard widely used in Europe, including all of Ireland. Some significant differences from ITE GB data occur, but a conversion table can provide assistance. However, as the MONARCH study is discovering, neither classification is completely satisfactory for field ecologists, as they tend to have different criteria when mapping plant communities from those derived by a remote sensing approach.

The ITE Land Cover Map was produced in 1990, and it can therefore be anticipated that, in some areas, significant changes may have occurred since then. Fortunately, as part of the Countryside Survey 2000 programme, a new UK land cover map is being produced which aims to identify all major broad habitat types using improved classification procedures. Countryside Survey 2000 also includes a sample-based field survey of sites throughout the UK which repeats surveys from the past 20 years, thus providing data on land cover changes.

Designated sites

A large proportion of the UK has been designated under various schemes for environmental protection. This includes protected conservation sites (i.e. SSSI, NNR, SAC, SPA, Ramsar) and those areas promoting agri-environmental schemes (notably ESA, NVZ and NSA). To justify the designation of these areas, a vast amount of data has accumulated, which if systematically organised will prove very useful for biodiversity studies and other research considering ecological impacts.

Data on the spatial distribution of conservation sites are available from the relevant conservation organisation in each country (namely English Nature, Countryside Council

for Wales, Scottish Natural Heritage and the Environment and Heritage Service, Northern Ireland). Given that there are about 10,000 SSSIs alone, this data-set by itself is important. However, additional data on the protected features at the site, when linked to the spatial pattern, can provide a record of the distribution of these features throughout the UK. Although there are problems with these data, as habitat mapping systems have not been standardised between agencies, the development of an integrated GIS containing these data for the MONARCH project, suggests that it provides a means of analysing schemes such as Biological Action Plan (BAP) habitats in a complete spatial context. It therefore becomes possible to map quite distinctive habitats or geological features from these data (e.g. semi-improved calcareous grassland, dry dwarf shrub heath, limestone pavements).

Topographic data

Detailed information on the nature of the local topography is very useful for several reasons. It often provides significant constraints on land use and infrastructure and is a very significant influence on other data-sets such as those from hydrology, soils, ecology and climatology. Elevation also indicates the likelihood of an area to experience flooding from adjacent rivers or the sea. For the UK, a base topographic data-set can be constructed from GTOPO satellite data (available from NASA) at a 1km grid scale. However, although this is very useful for reference purposes, and to visualise national-scale patterns, detailed work soon shows that it contains serious inaccuracies. Hence, topographic data are being utilised from two additional sources to fulfil the need for more accurate data at some locations:

- (i) Ordnance Survey Landform data: these are available at two scales 1:50,000 and 1:10,000. However limiting vertical accuracy is about 2-3m (maximum) which for some areas, such as the coastal zone, is not precise enough. Hence the use of :
- (ii) LIDAR data: these are high resolution data supplied by the Environment Agency, which have a vertical accuracy of ca. 10-15cm. Further

details are provided later in this Appendix.

Input of topographic data into a GIS allows the development of highly realistic 3D models of the landscape surface known as digital terrain models (DTMs) or alternatively, digital elevation models. DTMs are extremely useful visualisation and modelling tools and can provide valuable information for flooding and other hydrological studies. In addition, critical land-use factors can be derived, such as slope and aspect, which delimit the distribution of ecological and agricultural classes. For instance, in the REGIS study, 11° was defined as the threshold slope value for agricultural machinery; by masking out all slopes greater than this value, another constraint on the total croppable area for agriculture was imposed.

Administrative and socio-economic data

It becomes necessary when examining the results from studies, to display them in the context of administrative data (e.g. regions, local authorities, city boundaries). Other socio-economic data can be mapped to these administrative units for further detail. UKCIP currently holds a basic provision of these statistics. Current initiatives to provide more quantification to the UKCIP socio-economic scenarios (Section 1.2) also mean that a spatial pattern should eventually be derived from these and stored in the GIS. The REGIS project is already attempting to provide some of this quantification for the 5km grid squares in its study areas. Further baseline data are also available from the various national census that take place. In this context, one data-set currently in use is the MAFF annual census of farm returns: this is being used to validate the REGIS agricultural land use model (IMPEL) with present-day data, before extrapolating to future scenarios.

AI.2 Example data-sets from new technology

LIDAR (Light Detection and Ranging)

These are high-resolution elevation data derived from a special airborne instrument that samples the underlying ground height using the return time of a laser pulse across a swathe of land. The data are automatically geo-referenced by means of an on-board receiver linked to the Global Positioning System (GPS) of earth-orbiting satellites. Sample points are interpolated at 2m horizontal intervals with a vertical error range of only 10-15cm, which compares very favourably with the 2-3m limit for conventional Ordnance Survey data. Hence, these data are particularly valuable for the coastal zone and also for river floodplains.

The Environment Agency has obtained a large number of LIDAR data files, each covering 4km². However, present coverage is only a small fraction of the total UK land area and the main emphasis on data acquisition has been vulnerable coastal areas (notably East Anglia) where the risk has been perceived to be most critical. Some inland floodplains have also been surveyed (e.g. lower Severn, Trent, Welland) and other catchments are scheduled for survey in the near future, notably the Yorkshire Ouse. Nevertheless, for some areas, such as Wales and Scotland, there are very little or no LIDAR data at present.

The LIDAR data often contain a degree of background noise: vegetation, buildings and other objects may need to be removed to detect the true land surface, and this can be achieved by filtering and interpolation techniques relevant to the actual application. Currently, the data are being incorporated into the REGIS study for key areas to determine potential impacts of future coastal flooding. In the MONARCH study, the LIDAR data are being used to investigate changes in estuarine morphology that may occur due to sea-level rise from climate change, and the resultant impact on bird distribution.

SAR (Synthetic Aperture Radar)

Another technological development that is likely to prove useful to UKIP in the near future is application of interferometry data from SAR. These data can be delivered from an airborne or satellite platform, at a slightly lower accuracy than LIDAR. However, satellites can cover a much larger area than aircraft, therefore it should soon be feasible to construct a national-level data-set by this method at an increased accuracy than currently available from the Ordnance Survey, and with less technical constraints than LIDAR.

Bathymetry data

Wide-swath side-scan sonar offers the potential of a considerably improved knowledge of coastal processes. By combining the data with GPS information, it becomes possible to produce bathymetric maps of the sea-floor at a resolution unprecedented with echo sounders, as Environment Agency tests have already demonstrated. This will allow detailed survey and monitoring of offshore sediment dynamics, which are very sensitive to change and have major implications for coastal erosion and inundation under scenarios of rising sea-level.

Appendix 2

Review of pre-UKCIP climate change impacts assessments

Kate Lonsdale

AII.1 Introduction

A review of studies conducted outside the main UKCIP umbrella is important to place the work of the Programme in a wider context. A considerable amount of work has been done in some sectors, but the results are not always readily available, and coverage in some areas is incomplete.

This Appendix shows that several studies originated after the CCIRG review on climate change (CCIRG, 1996) in response to issues identified in that report. Although based on climate data that pre-date the arrival of the UKCIP98 scenarios, they contain findings and recommendations that still remain pertinent. Material in this Appendix collectively discusses these studies by sector, and then highlights further issues with a general overview.

It must be stressed that this review does not pretend to be a complete assessment of all climate change impacts studies completed in the UK between 1996 and 1998. It includes only those studies readily accessible in the public domain. It does not reflect, and so cannot do justice to, all climate change impacts studies initiated within the research programmes of major bodies such as the Environment Agency, MAFF, UK Research Councils, the EU and others. The intention of the review is, however, to give a flavour of the scope of UK climate change impacts work undertaken between the publication of the CCIRG (1996) report, and the launch of the UKCIP.

These limitations aside, useful insights have emerged from the review. These have been drawn upon to inform the research priorities

set out in Chapter 5 and to place the work of the UKCIP in a wider context.

AII.2 Approach

Studies included in this review have been analysed according to the follow structure:

- Study aims
- Scale of investigation
- Methods employed
- Data used
- Scenarios applied
- Key findings
- Gaps
- Recommendations for future work

Findings are presented On a sector by sector basis, reflecting the sectoral nature of many of the studies. For each sector, an attempt is made to assess the effectiveness of existing frameworks for supporting climate change impact research and implementing recommendations. It is necessary to identify for each sector whether there is a framework or a lead organisation that can identify future research priorities and disseminate the results to the sector. This information is not always readily available, although it is possible to gain a picture of the level of awareness of climate change in a sector and the stage at which research community is currently working. For example, is the research: a qualitative overview of likely potential impacts; an attempt to assess the likelihood of certain impacts occurring; or a consideration of how stakeholders might use the available information to make decisions, given the existing levels of uncertainty? Each of these three examples could be said to represent different stages of awareness of climate change

impacts. Priorities for next step research can thereby be explored.

AII.3 Sectoral overview of studies

Water resources

Material reviewed here reveals that the water resources sector has a strong framework for identifying research issues and carrying out research. A number of organisations are active in this: UK Water Industries Research (UKWIR), the Environment Agency (EA), the Institute of Hydrology (IoH) and universities. Water resource impacts due to climate change have thus been clearly identified. A report by the Environment Agency (Environment Agency, 1999) provides a literature review of impacts relevant to the Agency. A major UKWIR/EA study for the water industry used case studies of 60 catchments to develop a method allowing the rapid, strategic-level assessment of the effects of climate change on river flows and groundwater recharge (Arnell *et al.*, 1997). This provided the water companies with a method to include climate change in their AMP3 resource assessments, and built on previous work funded by the Department of the Environment. An overview of the main implications of climate change for UK water resources has been provided by Arnell (1998) and there have also been several other studies investigating potential impacts of climate change (Holt and Jones, 1998; Pilling and Jones, 1999; Sefton and Boorman, 1997).

MAFF has commissioned a number of research projects on the implications of climate change on water resources for agriculture (e.g. Weatherhead *et al.*, 1998). There has been only one report to date on the demand-side aspects of adapting to climate change (Herrington, 1998), although this is potentially an important way of mitigating climate change impacts on water resources. This report highlighted the dearth of detailed information available for analysis, and recommended that improved data should be collated to assist effective management of peak demand.

A high level of awareness of climate change in this sector is evident, as is a high level of

concern by the Environment Agency to incorporate the risk and uncertainty associated with climate change into the Environment Agency's planning time frames for large projects, such as reservoir construction. The Environment Agency also noted that most studies to date have simulated impacts in the absence of adaptation to change. In practice, water management systems will begin to adapt gradually to change.

Two main issues result from the review of this sector. First, much of the available information is based on model predictions rather than practical experimentation. While procedures to map and model water resources appear to work well at the national level, for more detailed regional or catchment-based assessments there is a much greater level of uncertainty associated with the model results. Changes in the frequencies of extreme events (such as floods and droughts) are likely to be very important for managing water resources. Catchment level data as well as daily or sub-daily precipitation data will be required in order to predict such events. The second issue relates to the availability of research results. Some research outputs have not been readily available for general use. It has been recognised in some studies, however, (e.g. Weatherhead *et al.* 1998), that ways of making information available at a local level should be considered. The dissemination of research results in a form that farmers can use to make decisions is also considered to be a priority.

Extreme events

Flooding

A lot of information on riverine and coastal flooding is available. However, very little work to date has dealt with the impacts of climate change on the frequency of extreme events. Although MAFF have funded research on changes in flood frequency (Reynard *et al.*, 1998), the Environment Agency (1999) report notes that the case studies on flooding undertaken so far in the UK have considered only annual and monthly river flows. Changes in the daily and sub-daily precipitation at the river basin scale are needed in order to determine changes in runoff responses for extreme events.

The extent of the increase in flooding under climate change is very uncertain and likely to vary greatly between catchments. The IPCC (Watson *et al.*, 1996) lists four main reasons for this uncertainty:

- It is difficult to define credible scenarios at the catchment scale for changes in precipitation that produce floods;
- It is difficult to model the processes that transform rainfall into floods (although there are many techniques and models available to attempt this and much experience in applying them to design and analysis of flood alleviation schemes);
- Available climatic and hydrological records have limited information about flooding;
- In many cases it is difficult to differentiate the effects of climate change from anthropogenic changes to land use.

A description of the nature of climate change impacts on flooding is given in Handmer *et al.*, (1999). Also included is a discussion of policy responses to increased flooding, with both conventional options and more radical alternatives. The history of flood hazard management is reviewed and the role of the Environment Agency in flood management is examined.

A risk assessment of coastal flooding areas was undertaken by Sir William Halcrow & Partners Ltd on behalf of the Association of British Insurers (Maddrell *et al.*, 1997). This research aimed to assess the risk of coastal flooding by examining the integrity of existing sea defences. This work built on data collected by the Sea Defence Survey conducted by the National Rivers Authority. The results of this study are commercially available.

The Environment Agency has a supervisory role for all flood risk management in England and Wales and directly promotes the construction, maintenance and management of flood alleviation schemes on all main rivers and lengths of coast. It aims to take a strategic view of flood defence planning and management, recognising that actions in one area can have significant impacts elsewhere.

Drought

The hot dry summer of 1995 brought to the fore the potential consequences of an increased likelihood of drought occurring in the UK due to climate change. This prompted two reports, (Palutikof *et al.*, 1997 and Orson, 1999) for the then Department of Environment and MAFF respectively. Both reports commented that responses to this event would provide insight into the likely effects of future droughts caused by climate change.

Despite this recent interest in drought there has been little work that directly connects climate change with the occurrence of drought in the UK. The report by Palutikof *et al* (1997) shows that drought has implications for all sectors. An integrated approach to assessing the effects of droughts would be valuable.

Ecological impacts

Considerable information on the impacts of climate change in this sector is available. The type of research being undertaken varies widely from observations of occurrence (e.g. the early appearance of the swallow), to experiments on the effects of elevated carbon dioxide concentrations on plants and investigations of analogue areas to try to determine impacts of climate change for future ecosystems. Major programmes to investigate climate change impacts in this sector include the Terrestrial Initiative on Global Environmental Research (TIGER), specifically the component on impacts on ecosystems, and Biological Adaptations to Global Environmental Change (BAGEC). Both programmes were funded by the Natural Environment Research Council (NERC). The work was carried out by many research institutions (60 for TIGER and 17 for BAGEC). Together these programmes developed an integrated community of scientists investigating the effects of climate change and their associated environmental factors (increased CO₂, UV-B, ozone (O₃)) on plants and animals. TIGER also had components that investigated the carbon cycle on land, trace greenhouse gases and energy and water budgets.

An important point to emerge from the body of literature on biodiversity impacts is captured in the Environment Agency's report

(Environment Agency 1999). That is: how should priorities be set for conserving biodiversity in a changing climate. The report identifies three options for what should be conserved: ecosystems in their pre-climate change state; 'naturalness' (for that location and climatic condition) and 'what people like'. It suggests that special attention should be focused on particularly vulnerable areas, such as wetlands in southern England, coastal marshes and montane communities.

Buildings and infrastructure

Material reviewed here suggests that research on climate change impacts in the building sector in the UK is still at quite an early stage. There have been few reviews of prospective impacts, impact assessments or geographical assessments. Most of the existing work has been carried out by the Building Research Establishment (BRE). Their report (Garvin *et al.*, 1998) describes itself as a first attempt to identify the key issues regarding climate change impacts on buildings and to 'develop an acceptance of reality'. Workshops with industry partners carried out in conjunction with this research found that climate change was viewed as being of 'low priority' by the industry generally and that little was known about the science or potential impacts.

The BRE also adopted a basic qualitative risk assessment methodology to assess impacts on building regulations. This provides a guide to regulators on which regulations require updating in the light of climate change. The BRE was identified at the workshop as being the organisation best suited to co-ordinating future research and disseminating research findings. Stakeholder participation in determining future research requirements was used by the BRE and it was suggested that this involvement should be developed further. One outcome of the workshop was a suggestion that climate change researchers need to work with the relevant technical committees to make the best use of scenarios.

There appears to be very little information about the effects of climate change on infrastructure beyond brief references in other reports (for example, the effect of increased temperature on road surface materials).

Planning

The planning sector is still in the early stages of awareness of the climate change issue. Although there are pockets of interest at a local level there is no obvious national framework or lead organisation to take responsibility for developing the climate change agenda. Despite this, many other sectors refer to the importance of planning as a mitigation tool. This is most apparent in the potential for planning legislation to prevent new development in flood-prone areas.

Insurance

The insurance industry, through the Association of British Insurers (ABI), has been investigating climate change impacts for a number of years and documents reviewed here note that sufficient information is now available for the industry to start to adapt to climate change. More information is currently being made available to the industry through the TSUNAMI project (TSUNAMI, 2000). This project aims to improve the competitiveness of the UK insurance industry by using the science community to improve the assessment of risk. This is achieved through applied research and direct collaboration on research projects. Through this and other ABI-funded research, such as the Halcrow coastal flooding research (Maddrell *et al.*, 1997), more precise underwriting is possible. The report suggests that the insurance industry could work more closely with local authority planners to ensure adequate control of development in flood-prone areas. There is a view that the industry should not be expected automatically to provide cover where regular flooding occurs, where remedial schemes have been refused at the local level or where development has taken place without due regard to adequate defence provision.

A large amount of information has been generated by the insurance industry on climate change impacts, both directly (through increased claims for climate-sensitive reasons such as subsidence, windstorm damage), and also in the results of research funded by the insurance industry. Much of this information is available only to the industry itself. Very little is in the public domain in a form that can

be used for decision-making or further research. Issues of data confidentiality are clearly a constraint that will need to be overcome if an industry-wide assessment of climate change impacts is to be undertaken.

Agriculture and forestry

The agriculture sector in England and Wales is probably the most thoroughly covered for climate change impacts research. The BAGEC programme (BBSRC, 1997) looked specifically at environmental changes that could be exploited to maximise the advantages of climate change to agriculture and minimise the disadvantageous effects. MAFF has funded a substantial research effort on all aspects of climate change impacts (to the order of around £5 million), from modelling farm-level responses (project number CC0333) to irrigation demand predictions (project number OC9219) and the economic implications of climate change for agriculture (project number CC0320). A great deal of information therefore exists on the sector. A booklet summarising the entire output of MAFF's programme of terrestrial research has been published recently in an attempt to disseminate findings from the programme to a wide audience (MAFF, 2000).

Material reviewed here suggests that climate change is low on the list of farmers' priorities, although there appears to be growing concern about potential impacts. As in the building sector, the difficulty of making decisions about the future, given existing levels of uncertainty, should be addressed. Presenting information in a form that is relevant to farmers, bearing in mind their time-scales for decision-making and the inertia to change caused by previous investments in their enterprises, may help them respond to the challenges they face.

Less information is available on research into climate change impacts in forestry. The Forestry Commission is currently developing models of tree growth and climate change. The importance of forests as carbon sinks has also been identified by the Commission and is being modelled. It is proposed that these models become units of a core model that includes forecasting, prediction of stand condition and ecosystem modelling.

Gaps

Several sectors were barely covered in the climate change impacts literature reviewed here. These include, for example, tourism, health, transport, retailing and manufacturing. For some sectors, which operate on short time scales, the 'wait and see' approach may be more reasonable. For those sectors with a longer-term planning frame, ways to incorporate potential climate change impacts must be considered. Many sectors appear reluctant to consider the threat of climate change, due to uncertainty surrounding the predictions. Tools to aid decision-making amid uncertainty are therefore required. From much of the research reviewed, it is noted that awareness-raising, targeted advice and information that is relevant to the decision-makers in each sector is necessary to encourage positive action. To make the message relevant, the key decision-makers (stakeholders) should engage in two-way communication with the research community and be involved in every stage of the research process.

It appears that the sectors that have progressed furthest in implementing climate change research have tended to be those which have a strong organisation or umbrella body that is willing to carry the research agenda forward. This seems to be the most effective way of focussing effort and producing information that can be disseminated efficiently to decision-makers, in a form that is relevant.

II.4 Cross-cutting issues

A number of common themes ran through many of the studies. In the scene-setting stages it was often stated that there was a dearth of information on the subject, that this was an 'initial stab' at addressing climate change impacts or that work in the area was in the 'early stages'. Five areas where gaps were apparent have been identified:

Data requirements

All the studies called for climate change information on higher resolution temporal and spatial scales, as well as information on associated risks in order to take the research

process beyond the initial recognition of the issue. Lack of local data to validate models was noted in the MAFF Irrigation study (Weatherhead *et al.*, 1998). The resulting model performed well at the national level but was less reliable at the regional and catchment levels. The Demand Management study (Herrington, 1998) highlighted the absence of good, historical water demand data for analysis. This report emphasised the importance of keeping accurate data in order to manage and predict future demand under the climate change scenarios. Improving the availability of reliable data for climate models will strengthen the predictions of climate change and narrow the range of assumptions, making it easier to make decisions about future action.

Some concern was expressed over the accuracy of data available for model validation. Some data-sets were found to be out of date and gave misleading results. Models used in a MAFF-funded project (Parry *et al.*, 1999, project number CC0320) need updating and this will be carried out as part of MAFF project CC0339 on the *Effects of climate change on agricultural land use in England and Wales*. The need to update databases was also noted in the Halcrow report on the state of sea defences, (Maddrell *et al.*, 1997) which recommended continual improvement and updating of databases and the need to periodically revise forecasts using new information. This report also noted that details were expensive and time consuming to collect. Models are thus used to try to simulate responses without the need for extensive data collection.

One final point concerns the need for a feedback process from the impact assessment community to the climate scientists. This stage is important, as the impacts community can identify which climate science parameters need to be improved to aid their impacts assessments.

Methodological issues

Much of the work reviewed here is in the early stages of impact identification and thus the favoured methodologies were either:

- a qualitative overview or literature review for a given sector (e.g. Garvin *et al.*, 1998; Environment Agency, 1999);
- scientific experimentation, often looking at just one parameter at a time e.g. the effects of temperature increases on aphid population dynamics (*BAGEC Programme*, BBSRC, 1997; *TIGER Programme*, NERC, 1996);
- modelling (e.g. Parry *et al.*, 1999).

Some projects used more than one method. Focus groups and facilitated workshops were used in the BRE building study (Garvin *et al.*, 1998, 1999) and 'expert judgement' was often called upon (e.g. Weatherhead *et al.*, 1998). Several of the projects state that the methodology used was a limitation and that with more resources it would be desirable to move beyond the basic research methodologies necessary to 'develop an acceptance of reality' (Garvin *et al.*, 1999). Some concerns over the limits of modelling were expressed e.g. a model that predicts enterprise effects rather than farm level effects restricts the model's ability accurately to predict future changes to land use, since structure varies considerably between farms and farm types. (Parry *et al.*, 1999).

Uncertainty

Many of the reports reviewed here were initial scoping studies that set the scene and identify potential impacts. There then seems to be some inertia in taking forward next steps, which may be due, in part, to uncertainty about the magnitude and severity of the spatial and temporal extent of climate change impacts. Reducing the level of uncertainty by increasing the accuracy of predictions, particularly at the regional level, is a priority area mentioned in the NERC's strategic plan (1999). In a number of the modelling studies accurate predictions were possible at the national level but as more regional or local information was required the level of uncertainty increased.

The Environment Agency (1999) report states: 'climate change is, essentially, an increase in the level of uncertainty of future supply and demand'. So, in addition to trying to reduce the level of uncertainty, coping with climate change is also about learning how to take

decisions amid uncertainty. Existing mechanisms for coping with uncertainty thus have to be looked at. The problems of making decisions given the large degree of uncertainty was emphasised in most of the projects. The high cost of taking action that was later deemed unnecessary was a concern. The Environment Agency report stated: 'due to the uncertainty surrounding climate change there is a risk that the Agency will be either blamed when it has not anticipated outcomes that are the results of climate change or that it blames climate change unjustifiably to cover up for management failure'.

Any action that is taken by an organisation in response to a climate change impact has an associated cost that needs to be justified. Deferring action will always look attractive in economic terms. The desire for a clear agenda on how to move forward on this was apparent. The development of decision tools was suggested as a way forward and at the stakeholder workshop run by the BRE, (Garvin *et al.*, 1999) it was suggested that choosing one scenario as a 'no regrets' choice would simplify the issues and make decisions easier. The use of analogues was also suggested (DETR 2000) although it was thought that there might be some cultural barriers to this. It is hoped that the UKCIP/EA study on Risk and Uncertainty in Decision-Making (see Section 1.2) will go some way towards addressing these concerns.

Process

Projects reviewed here tended to be initiated through a 'top-down' approach with limited stakeholder engagement in the project planning, execution and analysis. This was a limitation noted in the BRE focus group (Garvin *et al.*, 1999) which felt that the building sector should be kept informed of the outcome of climate change impacts research, and that a two-way flow of information should be maintained. This desire for more involvement of stakeholders in the research process to make the outcomes more relevant was also identified by Weatherhead *et al.* (1998). Their report noted that 'farmers' attitudes have a major bearing on investment and responses' and that 'the psychology of decision-making should be included in the

farm level models'. The farmers' attitudes to changes in business and risk management constrain the results of simple farm function models based on technology and economics. Thus, by including these attitudes in the models, a more realistic response pattern is created which is more likely to provide the kind of information required by farmers to make decisions.

The absence of an account of behavioural changes was also noted in the MAFF irrigation and water demand study (Weatherhead *et al.*, 1998.) The public perception of risk gives high priority to certain sectors (e.g. health issues and nature conservation). These perspectives should be taken into consideration in research recommendations and in the prioritisation of future work. Other process concerns include the need for integration between sectors as well as within sectors. One example of this is the NERC project '*Integrating social, economic and engineering dimensions into climate science*' (NERC, 1999). For effective implementation of research responses it was considered that, as far as possible, existing institutional pathways should be used. An effective means of ensuring that results are consistently built into forward planning is also required.

Communication

The communication of information and research outputs is a key theme in many of the studies. Projects such as the Climate Impacts LINK Programme (hosted by the Climatic Research Unit, University of East Anglia) and TSUNAMI seek to act as a bridge between different groups in the provision of relevant information. For LINK this is between the Hadley Centre and the climate change impacts research community and for TSUNAMI, between the climate change impacts research community and the insurance industry. Feedback from end-users to the impacts research community is necessary to create informed models that take account of human behaviour and decision-making processes, and for the end-users to receive information to help them make decisions.

Awareness-raising within each sector and among the general public is seen as a high

priority in much of the research. For the building and infrastructure sector the BRE workshop noted (Garvin *et al.*, 1999) that climate change currently had a low importance within the industry but that with improved and targeted information, possibly through a website, this could change. There is a desire for the transfer of clear and relevant information and expertise in all sectors, especially those which are currently highly stressed due to external factors, such as agriculture. In such sectors, climate change will inevitably assume a low priority if effective means to communicate the results of research are not established.

Indicators are generally seen as a clear way to communicate trends. Thus there is a need to choose indicators that are easily understandable and of public and policy relevance. The DETR indicators reports (Cannell *et al.*, 1999) are intended to be published annually and available at no cost.

The importance of developing channels of communication, both within each sector and between different sectors, has been identified in a number of studies. For example, the BRE report (Garvin *et al.*, 1998) calls for guidelines, collective action, sharing of knowledge, fora for discussion within the industry and voluntary action on minimising the negative impacts of climate change. The Halcrow report on identifying flooding areas for the insurance industry (Maddrell *et al.*, 1997) calls for more co-operation between interested parties, both locally and nationally, for example between the Association of British Insurers and local authority planners.

AII.5 Bibliography

Adeloye, A.J., Nawaz, N.R. and Montaseri, M. (1999). *Assessing the impacts of climate change water resources impacts using a Monte-Carlo simulation approach*. Proceedings of the 2nd Inter-Regional Conference on Environment-Water 99.

Arnell, N.W., Reynard, N.S., King, R., Prudhomme, C. and Branson, J. (1997). *Effects of Climate Change on River Flows and Groundwater Recharge*. UKWIR/Environment Agency. Report 97/CL/04/1.

Arnell, N.W. (1999a). *Effects of climate change on river flows and groundwater recharge: update with the 1998 UKCIP scenarios*. Report to Environment Agency. Department of Geography, University of Southampton.

Arnell, N.W. (1999b). *Effects of global warming on water resources: implications of multi-decadal variability and changes in year-to-year variability*. Report to Environment Agency. Department of Geography, University of Southampton.

BBSRC, (1997). *Proceedings of the Biological Adaptations to Global Environmental Change (BAGEC) Programme*.

Brampton, A. H. and Harfor, C.M. (1999). *Wave climate change. Indications from simple GCM outputs*. HR Wallingford Report No. TR 80.

Burgess, K.A. and Reeve, D. (Sir William Halcrow and Partners). (no date) *The development of a method for the assessment of sea defences and risk of flooding*, Association of British Insurers.

Cannell, M.G.R., Palutikof, J.P. and Sparks, T.H. (eds.) (1999). *Indicators of Climate Change in the UK*. Department of the Environment, Transport and the Regions. Available at <http://www.nbu.ac.uk/iccuk/>

Chief Scientists Group, (1999). *Review of MAFF's R&D on Climate Change Impacts and Water Resources*. Review Document.

CCIRG (1996). *Review of the Potential Effects of Climate Change on the United Kingdom*. HMSO, London.

Cotton, P.D., Carter, D.J.T., Allan, T.D., Challenor, P.G., Woolf, D., Wolf, J., Hargreaves, J.C., Flather, R.A., Bin, L., Holden, N. and Palmer, D. (1999). *JERICHO: Joint Evaluation of Remote Sensing Information for Coastal and Harbour Organisations*. Final Report to the British National Space Centre.

Dawson, A. G., Smith, D.E. and Dawson, S. (2000). *Potential impacts of climate change*

on sea levels in Scotland. Report for Scottish Natural Heritage. *In press*.

DETR (2000). *Potential UK Adaptation Strategies for Climate Change*.

ENTEC Riverine Flood Research Project – Foreword, no date.

Environment Agency, (1999). *The Implications of Climate Change for the Environment Agency*. Research and Development Publication 22.

Forestry Commission, (1999). *Catalogue of Research*.

Forestry Commission, (1999). *Research and Development Strategy*.

Garvin, S.L., Phillipson, M.C., Sanders, C.H., Hayles, C.S. and Dow, G.T. (1998). *Impact of Climate Change on Building*. Construction Research Communications.

Garvin, S.L., Sanders, C.H. and Phillipson, M.C. (1999). *Building Refurbishment and the Impact of Climate Change*. BRE Scottish Laboratory.

Garvin, S.L., Sanders, C.H. and Phillipson, M.C. (1999). *Impact of Climate Change on Building*, December 1998 Workshops Report, Internal Project Report. BRE Scottish Laboratory.

Handmer, J., Penning-Rowsell, E. and Tapsell, S. (1999). Flooding in a Warmer World: the View from Europe. In: T.E. Downing, Oolsthorn, A.J. and Tol, R.S.J. (Eds.) *Climate, Change and Risk*. Routledge, London.

Herrington, P. (1998). *Climate Change and the Demand for Water*. Environment Agency.

Hill, M.O., Downing, T.E., Berry, P.M., Coppins, B.J., Hammond, P.S., Marquiss, M., Roy, D.B., Telfer, M.G. and Welch, D. (1999). *Climate Changes and Scotland's Natural Heritage: an environmental audit*. Scottish Natural Heritage. Research, Survey and Monitoring Report No. 132.

Holt, C.P. and Jones, J.A.A. (1996). Equilibrium and transient global warming

scenarios: implications for water resources in England and Wales. *Water Resources Bulletin*, 32, 711-721.

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

Sefton, C.E.M. and Boorman, D.B. (1997). A regional investigation into climate change impacts on UK streamflows. *Journal of Hydrology*, 195, 26-44.

Hossell, J. (1999). *The Timescale of Potential Farm Level Responses and Adaptations to Climate Change in England and Wales*, Project Report, ADAS. MAFF project number CC0333.

Kitson, T. (1999). *The truth about water resources - a traverse from the wet west to the dry east*. Paper presented at the Climate Change Conference, ICC Birmingham. 26th May 1999.

Maddrell, R.J., Burgess, K.A. and Deakin, R. (Sir William Halcrow and Partners,) Mounsey, C.P. (ABI). (1997). *Identification of Coastal Flood Areas in England and Wales for the Insurance Industry*. Association of British Insurers.

MAFF. (2000). *Climate Change and Agriculture in the United Kingdom*. MAFF, London.

MAFF. (1998). *Development of a Set of Indicators for Sustainable Agriculture in the United Kingdom*. A consultation document.

Mounsey, C.P. (1999). *Insurance: the Big Event*. Paper given at the Ice Flood Seminar.

NERC. (1994). *Demonstrating Climate Change Impacts in the UK*. Department of the Environment Core Model Programme (1990-1994).

NERC. (1996). *The Tiger's Tale, Achievements of the NERC Research Programme*, Terrestrial Initiative in Global Environmental Research.

- NERC. (1999). *NERC Strategic Plan, 1999-2004*.
- Orson, J.H. (1999). *A review of the impact of the hot dry summer of 1995 on the main agricultural and horticultural enterprises in England and Wales*. MAFF. MAFF Project No. CC0322.
- Palutikof, J.P., Subak, S. and Agnew, M.D. (1997). *Economic Impacts of the Hot Summer and Unusually Warm Year of 1995*.
- Parry, M., Carson, I., Rehman, T., Tranter, R., Jones, P., Mortimer, D., Livermore, M. and Little, J. (1999). *Economic Implications of Climate Change on Agriculture in England and Wales*. Research Report Number 1, Jackson Environment Institute. MAFF project number CC0320.
- Rehfishch, M. and Austin, G. (1999). Ringed Plovers go east. *BTO News*, **223**, 14-15.
- Reynard, N.S., Prudhomme, C. and Crooks, S.M. (1998). *The potential impacts of climate change on the flood characteristics of a large catchment in the UK*. Proceedings of the 2nd International Conference on Climate and Water. Espoo, Finland, 17-20 August, 1998. pp.320-332.
- Stacey, D.A. (1999). Insect responses to warmer winters in the UK. *Aspects of Applied Biology*, **53**, 137-142.
- Sternberg, M., Brown, V.K., Masters, G.J. and Clarke, I.P. (2000). Calcareous grassland vegetation responses to the field manipulation of local climate. *Plant Ecology*, **143**, 29-37.
- Thompson, K., Masters, G.J., Grime, J.P., Brown, V.K., Clarke, I.P., Hillier, S.H., Askew, A.P., Corker, D. and KIELTY, J.P. (2000). Predicting the response of limestone grassland to climate change. *Aspects of Applied Biology*, **58**, in press.
- TSUNAMI (2000) The Tsunami initiative. Web page at <http://www.nbs.ac.uk/public/tsunami/>
- Watson, R.T., Zinyowera, M.C., Moss, R.H. and Dokken, D.J. (1996). *Impacts, Adaptations and Mitigation of Climate Change, Scientific-Technical Analyses*. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge, Cambridge University Press.
- Weatherhead, E.K., Knox, J.W., Morris, J., Hess, T.M., Bradley, R.I. and Sanders, C.L. (1998). *Irrigation Demand and On-Farm Water Conservation in England and Wales*. Final Report, Funded by MAFF. MAFF Project No. OC9219.

Appendix 3

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