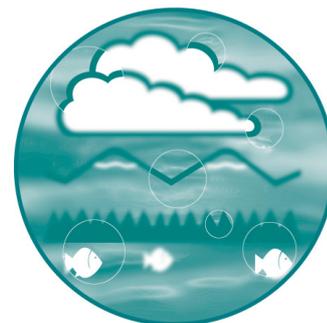
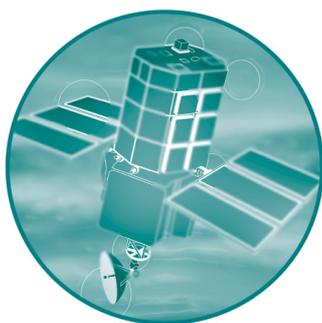


# **Defra/Environment Agency Flood and Coastal Defence R&D Programme**



## **UK Climate Impacts Programme 2002 Climate Change Scenarios: Implementation for Flood and Coastal Defence: Guidance for Users**

**R&D Project Record W5B-029/PR**



**UK Climate Impacts Programme 2002 Climate Change  
Scenarios: Implementation for Flood and Coastal Defence:  
Guidance for Users**

R&D Project Record W5B-029/PR

Research Contractor: Peter Hawkes, Steven Wade  
HR Wallingford

**Publishing organisation**

Environment Agency, Rio House, Waterside Drive, Aztec West, Almondsbury, Bristol BS32 4UD

Tel:01454 624400 Fax: 01454 624400 [www.environment-agency.gov.uk](http://www.environment-agency.gov.uk)

© Environment Agency April 2003

ISBN 1 844 32089 8

*The Environment Agency will waive its normal copyright restrictions, and allow this document (or other item), excluding the logo to be reproduced free of licence or royalty charges in any form, provided that it is reproduced unaltered in its entirety and its source acknowledged as Environment Agency copyright.*

*This waiver is limited to this document (or other item) and is not applicable to any other Environment Agency copyright material, unless specifically stated. The Environment Agency accepts no responsibility whatever for the appropriateness of any intended usage of the document, or for any conclusions formed as a result of its amalgamation or association with any other material.*

*The views expressed in this document are not necessarily those of Defra or the Environment Agency. Its officers, servants or agents accept no liability whatsoever for any loss or damage arising from the interpretation or use of the information, or reliance upon views contained herein.*

**Dissemination status**

Internal: Released Internally

External: Publicly Available

**Statement of use**

This document provides information for flood risk and coastal management in England and Wales about use of the UKCIP02 climate change scenarios. It constitutes an R&D output from the Joint Defra / Environment Agency Flood and Coastal Defence R&D Programme.

**Keywords**

Climate change, flood risk, precautionary allowance, rainfall, river flow, sea level rise, wind speed, wave, flood defences, river and coastal, UKCIP02.

**Research Contractor**

Name, address and contact details of the research contractor: Dr Peter Hawkes, HR Wallingford, Howbery Park, Wallingford, Oxon, OX10 8BA email [pjh@hrwallingford.co.uk](mailto:pjh@hrwallingford.co.uk)  
This report also constitutes HR Wallingford Report SR 613.

**Defra / Environment Agency Project Manager**

The Client Project Manager was Dr Suresh Surendran of the Environment Agency's Environmental Policy Centre for Risk and Forecasting, Kings Meadow House, Kings Meadow Road, Reading RG1 8DQ, email [suresh.surendran@environment-agency.gov.uk](mailto:suresh.surendran@environment-agency.gov.uk).

Further copies of this report are available from:  
Environment Agency R&D Dissemination Centre, c/o  
WRc, Frankland Road, Swindon, Wilts SN5 8YF



tel: 01793-865000 fax: 01793-514562 e-mail: [publications@wreplc.co.uk](mailto:publications@wreplc.co.uk)

R&D PROJECT RECORD W5B-029/PR

## **FOREWORD**

This work was funded by the Environment Agency, as R&D Project W5B-029: Climate change scenarios UKCIP02: Implementation for flood and coastal defence. The Project Manager for HR Wallingford was Dr Peter Hawkes, assisted by colleagues Dr Paul Samuels, Dr Alan Brampton and Dr Keith Powell. The Project Manager for WS Atkins Consulting was Dr Steven Wade, assisted by colleagues Dr Rob Wilby and Jonathan McCue. The Client Project Manager for the Environment Agency was originally Dr Nick Reynard and subsequently Dr Suresh Surendran. The project was undertaken under the joint Agency / Defra research theme Risk Evaluation and Understanding of Uncertainty, headed by Ian Meadowcroft.

### **Acknowledgements**

The authors are grateful for extensive and helpful comments provided by Nick Reynard (CEH Wallingford), David Richardson (Defra) and Iain Brown (UKCIP). Also, for encouragement and comment to Suresh Surendran, Jason Lowe (Hadley Centre), Richard Horrocks and Ian Meadowcroft (Environment Agency). Others involved in the telephone survey of user requirements are acknowledged in Appendix 1 of Environment Agency / Defra (2002b). Acknowledgement here or in the telephone survey appendix does not imply endorsement of this report's comments and conclusions.

No climate change modelling was undertaken within the present project. The UKCIP02 scenarios were prepared and interpreted by the Tyndall Centre, the Hadley Centre and UKCIP, with funding provided by Defra.

## EXECUTIVE SUMMARY

This report addresses the use of future climate change information within the flood and coastal defence community of England and Wales. It reviews the requirements and opinions of the users and sets them alongside the information available from the UKCIP02 climate change scenarios. Where necessary, it recommends further research needed to facilitate consistent use of the future climate change information within the flood and coastal defence community.

National allowances for future sea level rise and hydrology are the only commonly used future climate changes, although river flow or wave modelling is sometimes undertaken. Most users do not want discretion in quantifying and applying future climate change. They would prefer consistent straightforward guidelines, ideally in the form of contour maps of rainfall change, wave height change and sea level rise. There was a feeling that climate change calculations should focus more on the overall *consequences* of change than they do at present, and that they should be considered in the context of the many other uncertainties involved. The general uncertainty and lack of confidence in predictions of extremes concerned some users. The existence of four alternative future climate scenarios also presents a problem, without a developed policy for their use. Once established and accepted, most users argued for applying the guidance consistently and not changing it unless really necessary.

Climate change scenarios provide a starting point for assessing climate change vulnerability, impact and adaptation. UKCIP released new future climate scenarios in April 2002. Variables saved directly from the climate model runs include sea level rise, wind speed and direction, precipitation and soil moisture. Additional variables derived in subsequent modelling include surges and ocean currents, but wave conditions and river flows would involve further modelling and interpretation not yet undertaken.

The following topics are recommended for further research needed to increase take-up of climate change scenarios by river and coastal engineers:

- refinement of extreme river flow and flood risk studies, as compared to the present 20% precautionary allowance
- refinement of extreme sea level projections to narrow the range of uncertainty, particularly in the Thames and Anglian regions
- modelling of wave climate and extremes
- modelling of impact on coastal defences and standard of service
- predictions for short duration rainfall for drainage studies
- modelling of impact on coastal morphology

The accompanying Guidance for Users (Environment Agency / Defra, 2003) provides more detailed guidance intended for actual use in applying the UKCIP02 climate change information over a range of activities related to flood and coastal defence.

# CONTENTS

<b>Executive Summary</b>	<b>ii</b>
<b>Acronyms</b>	<b>v</b>
<b>1 Introduction</b>	<b>1</b>
1.1 Background	1
1.2 Scope of the project	1
<b>2 User needs for climate change information</b>	<b>3</b>
2.1 Approaches to information gathering	3
2.2 Which existing work elements consider future climate change?	4
2.3 How is climate change included at present?	5
2.4 Would different information, formats or techniques be preferred?	6
2.5 What are the known faults, difficulties and uncertainties?	8
2.6 Additional information requirements, applications and research needs	9
2.7 Summary of main points	11
<b>3 UKCIP02 future climate scenario components</b>	<b>12</b>
3.1 Climate models and scenarios	12
3.2 Rainfall	13
3.3 Sea level	14
3.4 Wind speed	16
3.5 Soil moisture	17
3.6 Uncertainties	18
<b>4 Recommendations</b>	<b>19</b>
4.1 Which user needs can already be addressed?	19
4.2 Which user needs require further research?	20
4.3 Research requirements	21
4.4 Other research ideas	23
<b>5 References</b>	<b>25</b>

## Figures

Figure 1	Percentage change in the 2-year return period daily precipitation between now and the 2080s (reproduced from UKCIP02 showing increases of up to 25% in Winter and decreases of up to 30% in Summer)	14
Figure 2a	Increase in the 50-year return period sea level between now and the 2080s under the Low Emissions scenario (reproduced from UKCIP02 showing increases of around 0.2m for most of the UK but up to 0.8m in the Thames estuary)	15
Figure 2b	Increase in the 50-year return period sea level between now and the 2080s under the Medium-High Emissions scenario (reproduced from UKCIP02 showing increases of around 0.4m for most of the UK but up to 1.2m in the Thames estuary)	15
Figure 2c	Increase in the 50-year return period sea level between now and the 2080s under the High Emissions scenario (reproduced from UKCIP02 showing increases of around 0.7m for most of the UK but up to 1.5m in the Thames estuary)	16
Figure 3	Percentage change in the 2-year return period daily averaged wind speed between now and the 2080s (reproduced from UKCIP02 showing increases of up to about 6% in Winter and decreases of up to about 7% in Summer)	17

## Table

Table 1	Description of four scenarios used in UKCIP02	12
---------	---	----

## Appendices

Appendix 1	Telephone interview logs	29
Appendix 2	Outline proposals for further research requirements	51

## ACRONYMS

CEH	Centre for Ecology and Hydrology
CFMP	Catchment Flood Management Plan
Defra	Department for Environment, Food and Rural Affairs
ECHAM	German climate model
FEH	Flood Estimation Handbook
GCM	Global Climate Model
HadCM3	British climate model
IFPM	Indicative Flood Plain Map
LA	Local Authority
MAFF	Ministry of Agriculture, Fisheries and Food (now Defra)
PAG	Project Appraisal Guidance
POL	Proudman Oceanographic Laboratory
PPG	Planning Policy Guidance
PR	Project Record
REUU	Risk Evaluation and Understanding of Uncertainty
SCOPAC	Standing Conference on Problems Associated with the Coastline
SLR	Sea Level Rise
SMP	Shoreline Management Plan
SRES	Special Report on Emissions Scenarios
TR	Technical Report
UKCIP	United Kingdom Climate Impacts Programme
UKCIP02	UKCIP Climate Scenarios 2002
UKCIP98	UKCIP Climate Scenarios 1998



# **1 INTRODUCTION**

This project addresses the use of future climate change information within the flood and coastal defence community of England and Wales. The Project Record (this document) reviews the present situation and possible future research requirements. The Guidance for Users (Environment Agency / Defra, 2003) provides more detailed guidance on the application of the scenarios, intended for day-to-day use in flood and coastal engineering studies.

## **1.1 Background**

The Hadley Centre for Climate Prediction and Research runs the UK global climate model, and a series of regional models at various resolutions, providing the raw information for future climate scenarios. The Hadley Centre also ran the operational surge model to provide input to the UKCIP02 extreme sea level assessment. Much of this is further processed by groups such as the Tyndall Centre and the Climatic Research Unit, both at the University of East Anglia, to develop the raw model data into structured scenarios using appropriate techniques such as scaling and temporal aggregation. The United Kingdom Climate Impacts Programme (UKCIP) provides generic guidance to stakeholders across many sectors of interest on the application of these scenarios in a consistent and appropriate manner. The UKCIP 1998 climate change scenarios were not widely used within the flood and coastal defence community, but it is hoped that the 2002 scenarios (UKCIP, 2002a, 2002b) with their increased spatial and temporal resolution and additional variables, will find greater application.

The purpose of the present project (W5B-029) was to identify which elements of UKCIP02 are most relevant for use in flood and coastal engineering, and if necessary to outline further research and data processing needed to assist that usage. The ideal outcome would be consistent and implementable guidelines for estimating future changes in waves, water levels, rainfall, river flows etc. around the UK, together with notes on which variables need to be considered for particular design and assessment procedures. Different types of decisions require different levels of climate change assessment. Where possible, the guidance notes which data to use, whether full modelling of an input variable is needed or whether a simple allowance would be adequate, and whether full modelling of an outcome is justified or whether a sensitivity test would be adequate.

## **1.2 Scope of the project**

The project commenced in August 2001. The main project elements were as follows:

1. To review climate change information needs from the viewpoints of a range of decision makers. This was assisted by a programme of organised telephone interviews with 13 individuals in the flood and coastal defence community.
2. To review the components of the UKCIP02 scenarios in the light of the flood and coastal defence user needs.

3. Establish needs for further research, and scope out a programme of research topics to address those needs.
4. Produce practical guidance for decision makers, in the form of a report and a training workshop.

Three of the main project elements are described in this report, namely flood and coastal defence industry requirements, UKCIP02 variables and accessibility, and further research needed to facilitate take-up. The Guidance for Users (Environment Agency / Defra, 2003) provides guidance on use of the UKCIP02 information in different flood and coastal defence applications.

Advice on how the four different future emissions scenarios (High Emissions, Medium-High Emissions, Medium-Low Emissions, and Low Emissions) should be used in any particular application is outside the scope of the present project, but is considered in Environment Agency (2000). Advice on the appropriate level of assessment, taking account of the relative risks and uncertainties involved, is given in UKCIP / Environment Agency (2002). Information on the developing risk-based approach to flood management is given in Defra / Environment Agency (2002). Accuracy of the UKCIP02 information is not a key issue, so much as credibility and internal consistency, as it is given in the form of scenarios rather than predictions, but uncertainties and levels of confidence are addressed in UKCIP02.

These reports, together with the UKCIP02 information and any subsequent research which may be needed to facilitate take-up, are intended for use throughout the flood and coastal defence community. Users will include Defra, the Environment Agency, local authorities, consultants, developers etc. Activities will include Section 105 flood mapping, assessment of defences, catchment and shoreline management plans, flood risk mapping, project appraisal, values of national assets at risk etc.

MITCH (MITigation of Climate induced natural Hazards) is an ongoing Concerted Action funded by the European Commission, with support from the Environment Agency. It provides a forum for discussion of the wider impacts of climate change on natural hazards including flooding at <http://www.mitch-ec.net>. The site includes many links to other projects and web-sites concerned with either flood risk or climate change.

## 2 USER NEEDS FOR CLIMATE CHANGE INFORMATION

### 2.1 Approaches to information gathering

The aim was to consider any aspect of flood and coastal defence work which either already involves some element of future climate change, or which might use climate change information if it were available in suitable form. This review was intended to be comprehensive, even if some aspects would require new research before they could be addressed in a meaningful way.

Information was gathered from the experiences of the Project Team and the Project Board, and from organised telephone interviews with about a dozen others not directly connected with the project. The intention was to consider climate change issues across the physical range of coastal, river and economics, and the occupational range of regulation, design, operations and research.

The interviews lasted about thirty minutes and were structured around six questions:

*Which aspects of your work require consideration of future climate change?*

*How do you deal with them at present?*

*Would you prefer to deal with them differently? Do you use UKCIP98 data? What information formats do / would you prefer?*

*Do you know of any specific faults, difficulties, uncertainties, lack of data, situations not well dealt with at present?*

*Do you have any additional information requirement or research need?*

*What would you put on your wish list (whether practical or not) and which would be top priority?*

The interview logs are reproduced in Appendix 1, two with members of the Project Board and eleven with others in the flood and coastal defence community.

Sections 2.2-2.6 of this chapter are based on all information gathered, although they are structured in the same way as the telephone interviews (the last two questions being combined in Section 2.6). The points are in most cases taken directly from the telephone interviews, but are clarified and grouped to some extent, arranged in approximate order of importance, and where relevant a note is added as to how the point(s) will be (or can already be) addressed.

The inclusion of a particular point in Sections 2.2-2.6 does not necessarily imply the agreement of the project or client teams. However, where appropriate, the considered view of the client team is given in italics. The most significant general points are summarised in Section 2.7.

## **2.2 Which existing work elements consider future climate change?**

1. The impact of future climate change on economic assessments for new and existing coastal and river defences, usually calculated by designers and checked by regulators (for example Defra Regional Engineers) using Defra Project Appraisal Guidance (PAG) allowances for sea level rise and river flow.
2. The impact of future climate change on the residual life of existing coastal and river defences, and the design and procurement of new defences: a rather similar task to Point 1, again involving designers and regulators.
3. Assessment of flood risk and how it might change in future, including Planning Guidance (PPG25), Catchment Flood Management Plans, Flood Strategy Plans, Section 105, Coastal Flood Management Plans, Shoreline Management Plans (SMP) and coastal strategy studies. There is more scope here for introducing local data and knowledge into these strategic local studies.
4. Assessment of pumped drainage requirements, and how they might change in the future; assessment of land drainage consents. Systems in lowland areas depend upon water storage, volume requirement depending on storm frequency and intensity.
5. Regulation and vetting of above, all of which are already undertaken routinely using consistent approaches, particularly with regard to central government funding for locally promoted schemes. This tends to involve regulators checking that accepted methods have been applied consistently.
6. Assessment of the value of national assets at risk of flooding and how this might change in the future. This type of assessment has already been funded by Defra to assist in development of a national policy for flood and coastal defence investment: example modelling and calculations were done for several areas, from which national values were inferred.
7. Planning consents and assessment of land for new developments in potentially vulnerable areas may require specific consideration of climate change.
8. Identification and extension of potentially vulnerable areas needing flood forecast warnings.
9. Communication of flood risk issues to the public (awareness and acceptance) and elected representatives (policy and funding).
10. Continuing development of an integrated framework for management of flood risk.

Related issues mentioned by interviewees but outside the scope of this study were land-use change, climate change impacts on tourism and home energy assessment, and assessment of uncertainties and alternative future climate scenarios.

### 2.3 How is climate change included at present?

Where relevant, expected future sea level rise is always considered, potential future increase in rainfall and fluvial flow is usually considered, and potential future changes in wave conditions and storminess are sometimes considered. There is usually some assessment of one or more consequence(s) of climate change, in terms of increased overtopping rate, increased flood frequency or extent, increased defence height, increased annual average loss, reduction in standard of service etc.

1. The rate of future sea level rise (4 or 5 or 6mm/yr) is nearly always taken from MAFF (1999) Project Appraisal Guidance, but users appear to have some discretion on how many years (for example 50 or 100) of rise to consider.
2. The usual approach for future fluvial risk is to assume a 20% increase in the 100 year river flow by the 2050s, based on a note in MAFF (2000) Project Appraisal Guidance. One interviewee suggested that PPG25 Appendix F using the Flood Estimation Handbook (FEH) would lead to an assumed increase of 25-30%, but this is the subject of ongoing research under Agency / Defra R&D project W5B-01-050 at CEH Wallingford.
3. There is no national guideline for wave climate change, and where applied it tends to be as a sensitivity test, assuming a possible but arbitrary change in wave height or direction, or looking at the worst spell of a few years in a much longer hindcast period (ie based on past climate variability). For the moment, there is insufficient confidence in future wind conditions to justify routine use of a more sophisticated wave prediction method.
4. Some interviewees had the impression that the frequency of very severe events, particularly those resulting in fluvial flooding, has increased over the last few years, but there is no particular guidance or design action taken. Whether climate change or just natural variability, there has been an impact in some areas in recent years, in terms of increased fluvial flooding, and in terms of increased maintenance of drainage pumps and vulnerable soft coastal defences in order to maintain the same standard of service. They suggested that local data might be taken into account, although this is rarely done at present and then only if past trend is agreed to be a reliable indicator of future trend (eg long-term tide gauge). In passing, one interviewee commented that conservation considerations could prejudice maintenance drainage standards and other defences.
5. Climate change impact calculations tend to be done as sensitivity tests, for example to determine the impact on flood risk or scheme benefit / cost of specified change(s) in sea level, flow rate, wave height etc. Continuous simulation and/or joint probability methods are sometimes used. These calculations rarely affect scheme selection, but they may indicate the necessity for a design to be capable of being upgraded if and when future climate change happens.
6. Defra recommends and monitors appropriate and consistent use of national and regional allowances for future climate change, offering advice as necessary. One interviewee mentioned the 'Nottingham Climate Change Declaration', whose participants agree to support the national government line on climate change and impact assessment. Regional scenario-based climate change impact assessment reports are also used, where these are

generally accepted as being more relevant to particular local areas, for example the SCOPAC and South-West areas.

7. Coastal morphological change, in the form of cliff recession, siltation, beach development and erosion, is difficult enough to predict in broadly constant sea and weather conditions. Calculations can be re-run under changed mean sea level and/or changed wave conditions, but these are subject to great uncertainty.
8. In ring-defended areas, check that the flood defence design can cope with potential future flood conditions.
9. None of the interviewees use UKCIP98, but some had heard of it being used. All seemed prepared to consider using UKCIP02 if results and guidance are clear enough. One member of the Project Team uses UKCIP98 in PPG25 risk assessment work.
10. Clearer, less technical approaches, perhaps addressing final impacts directly, may be preferred in dealings with the public, but take opportunities to raise the general issues of climate change and consequences.

#### **2.4 Would different information, formats or techniques be preferred?**

As in Sections 2.2 and 2.3 the comments in this section are collated from the telephone interviews and other comments received, and do not necessarily reflect the views of the project or client teams.

1. Information provided by UKCIP02 and associated guidelines must be as meaningful, practical and unambiguous as possible. Try to keep the effort involved in individual application studies to a minimum; most users would prefer to be given simple rules and allowances, rather than having to work from first principles in each study. Users wanted to avoid the situation where lots of different figures are quoted and the potential climate impacts are misunderstood or misapplied. (One interviewee dissented from this view, saying that he would prefer greater flexibility and ability to incorporate uncertainties explicitly.)
2. The most useful form of future climate change information would be maps of changes in flood flow occurrence in rivers (or rainfall if rivers are too difficult to generalise), of future relative extreme sea levels around the coast, and of future wave climates (ie not climate model output, rather derived from separate modelling of derived variables). However, the derivation of these requires not only model outputs, but also high-level policy input as to where reasonable limits should be drawn. It is probably better to adopt simple generalisations unless some confidence can be attached to regional variations and likelihood of scenarios. Since investment decisions are being made that affect flood management over the next 50 years, recommendations should not be changed frequently unless there is very good reason to do so, as this can generate significant concern and unnecessary activity in revisiting decisions previously made.
3. Users would like to be provided with plausible and easy-to-apply rules for sea level rise, rainfall increase and wave height change, published by acknowledged researchers (eg UKCIP, HRW, CEH, POL) and clearly supported by regulatory authorities (Defra / Agency). Prefer clear and prescribed advice on how and what to do, even if figures are

contingencies rather than predictions. One reviewer noted that there is an unavoidable contradiction between what users want (prescribed contingency figures) and what is scientifically justifiable (a range of future scenarios with unknown probabilities of occurrence).

4. The Agency and others require robust defensible approaches that can be easily applied, involving a level of study appropriate to the potential consequences of climate change and to the confidence in the climate change scenarios. Appropriate advice should be prepared and agreed at a national level, but could be targeted at national, regional and local levels, at different types of user and usage, and at different periods into the future (about 15 to 100 years). Case studies may be helpful, to illustrate application in CFMP, SMP etc. CD / Internet / GIS access to numbers to be used in calculations would be helpful.
5. There should continue to be limited discretion not to follow national guidelines where this is agreed in advance with regulators in particular cases. There may be good local data not considered at national level, or local geographical characteristics not represented within a 50km grid climate model. It may be better to design for well documented local conditions, for example local storm characteristics, locally measured rainfall or locally measured relative sea level rise where this is not consistent with national guidelines.
6. Any guidance relating to river flows should sit well with FEH approaches, and ideally would be built in to the existing software, perhaps assisted by separate GIS macros or spreadsheet applications or nomograph solutions. For example, if the climate scenarios suggest shorter, sharper storms then this should be fed into the storm profile shape used to estimate flood hydrographs. It would be useful to have different increases in flow volume for different types of catchment or tables of climate change factors by broad hydrological criteria (eg location, geology, size). Similarly, changes in storminess need to fit in with standard surge analysis approaches, with effects varying along the coast.
7. Climate change assessment should include economic, social and environmental impacts, preferably in one overall approach within each management unit. If possible, provide climate change information in a form suitable for direct input to impact modelling and calculations.
8. One interviewee suggested that it would be more efficient to include for sea level rise in design and construction now, for example making walls 0.25m higher. It seems inefficient and to involve greater cost over the design life to revisit designs and upgrade walls, which could have been designed and built to allow for sea level rise originally (eg Humber).
9. One reviewer wanted to emphasise that the present system of precautionary allowances should be regarded as 'contingency figures', and that decisions could be reviewed regularly as better climate change information becomes available.
10. There is a need for information and formats that will promote awareness amongst the public and amongst developers (maybe different information than that intended for technical users).

## 2.5 What are the known faults, difficulties and uncertainties?

1. The general uncertainty and lack of confidence in predictions of extremes concerned some interviewees. This uncertainty can probably only be reduced by much greater understanding of the drivers for extreme events and the critical combinations of events at different times and spatial scales that lead to such extremes. This is recognised as an important issue by climate change researchers and, prior to UKCIP02, the climate scenarios were not considered accurate enough to provide information on extremes.
2. Climate change calculations in support of flood risk assessment often focus on derivation of a best estimate for wave height change, river flow change, beach drift change etc. It might be better instead to focus on possible impacts on decisions, for example whether a decision based on present-day climate would be sustainable in the future or whether an alternative defence strategy might be better. Similarly, there is a tendency to spend a lot of time on detailed (if very uncertain) climate change calculations, without considering that other risks, uncertainties in data and process modelling, and natural variations may have greater impacts on decisions. These two points are relevant to discussion of an appropriate level of detail and precision for climate change assessments.
3. UKCIP98 is on too coarse a grid for use in site-specific flood risk assessments, covering the whole of the UK in just four grid squares. Without additional guidance, it offers too much discretion for practical engineering use, for example a wide range of possible sea level rise scenarios. (UKCIP02 has better spatial resolution, and associated guidelines could assist in limiting inappropriate discretion in individual applications).
4. The four climate change scenarios in UKCIP give many decision-makers a difficulty, in the absence of a developed policy in each case (eg for a particular decision, take the Medium-High Emissions scenario). Scenario modelling can be undertaken, but it is difficult to develop this type of policy in the absence of any information on the relative likelihoods of a range of outcomes. Probability information would also directly support and be compatible with Defra and Agency stated moves towards risk-based decision-making.
5. Uncertainties are unquantified in the present precautionary engineering approach, but perhaps they should be identified, could be reduced, and could be evaluated and combined with the many other uncertainties.
6. Problems with climate change allowance occur due to the nature of the planning system. The Agency applies the precautionary principle but to refuse an application there needs to be a demonstrable impact of development on the environment. With climate change the precautionary principle might encourage the use of the most extreme climate scenarios but the impacts are hard to prove.
7. Some interviewees requested information on antecedent conditions especially ground water and soil moisture. Others mentioned storm sequences, in some cases very important for beach volume and alignment. Wind direction, strength and duration are also of interest.
8. Integrate information from the UKCIP scenarios with continuous simulation and other approaches to impact assessment. (This is being done.)

9. Joint probability is an issue, both due to cross-parameter dependence (eg waves / surge and surge / river flow) and due to spatial dependence (eg high flows simultaneously in different catchments). It may not be practical to model potential future changes in dependence, but failure probability can be sensitive to dependence.
10. Local knowledge, data and events are often not incorporated into national guidelines, even where they show that the national guidelines are locally inappropriate, arguing for local discretion in agreed cases.

## 2.6 Additional information requirements, applications and research needs

In this section, the sentence in italics represents the view of the project team and funders in response to the issue raised in that paragraph.

1. Most interviewees expressed a desire for reliable predictions of future climate change based on sound science (or, failing that, realistic and acceptable contingency allowances) and practical methods for impact assessment. *There is agreement between all concerned to work towards this vision for climate change assessment.*
2. Users requested clear guidance on which scenario and which parameters to use in different applications, provided for example in the form of the present Defra guidance (MAFF, 1999) on future sea level rise. As a minimum, this guidance would include best estimates of sea level rise, rainfall and wave height. If possible, it would also include river flow, wind speed, wave direction, uncertainties and extremes. If generalised calculation of future river flow is impractical, then develop software for automated conversion from rainfall through to river flow. *Generally, these points are accepted as desirable and there will be an attempt to address them, but they do illustrate a common misunderstanding of the scenario approach, in which the likelihood of occurrence is not estimated, and which cannot therefore provide a meaningful 'best estimate'.*
3. Users hoped that the regulatory authorities would reach national agreement as to what the different scenarios mean, and what the Agency and others should be doing and evaluating in response. This would include agreement on how to apply the information in design, CFMP, SMP PPG25, Section 105, town planning, emergency planning and at the local level, and would address consistent adoption of data and methods. The majority was against regular updates of the future climate change information, preferring to change only when really necessary to avoid disruption to methods and decisions. *Generally, these points are accepted as practical in support of the desire to reach pragmatic and robust investment decisions, and they will gradually be addressed, but given the uncertainty and need for possibly reversible decisions based on new climate change information, then the constrained approach might ultimately not be the best.*
4. Users requested that any necessary training would be provided, together with easy unambiguous access to actual numbers via contour maps, spreadsheet, CD, Internet etc. *Apart from the two reports and final open meeting at which they will be launched, this goes beyond the scope of the present project, but is consistent with the agreed principle of making all information available and all methods implementable.*

5. Catchment wetness data would be useful, as well as rainfall intensities for a range of durations from one hour upwards, with any future changes in seasonal variation. Changes in short-term extremes which contribute to flash flooding may not be well represented by changes in daily and seasonal characteristics given in UKCIP02. *Catchment wetness and seasonality are discussed in UKCIP02, and rainfall intensities for a range of durations has been logged as a further research topic (although very short term flash flooding will be difficult to model).*
6. The FSR rainfall-runoff model should be updated so that current flood estimates are based on an analysis of recent historic data. It would be possible to alter the model parameters to look the sensitivity of flood estimates to changing climate inputs but prefer to use gauged records and the FEH statistical approach. In this case it would be most useful to have estimates of changes in flow that could be used to alter the outputs of a FEH statistical flood estimate. The simplest way to perturb a gauged annual maxima series would be to change the mean and variance (or similar parameter) of the distribution by factors for each climate change scenario. It might be useful if FEH could include volume data sets so that pooling could be undertaken on volume as well as peak flows. Possibly need continuous simulation on a range of catchments to provide seasonal variations in the volume of flood peaks. *This is the subject of ongoing research (Agency / Defra project W5B-01-050) under the climate change theme at CEH Wallingford; Jeremy Benn Associates in collaboration with WS Atkins are working on an extreme flood outline study under the Environment Agency Section 105 programme.*
7. The 50km climate model resolution seems about right for actual use in preparing the guidance, although some locations may be affected by smaller scale geographical features not represented on a 50km grid. *Hopefully, the improved 50km resolution in UKCIP02 will increase take-up of results compared to UKCIP98.*
8. Better methods could be developed for quantification of flood risk area and frequency of flooding, and how it may change over the next 5 to 100 years. *This is in line with Defra policy, but does not fall within the scope of the present project.*
9. Any change in the frequency, intensity and sequencing of storms may have different effects to those which might be predicted from daily mean wind velocities, and changes in storm track may affect different areas differently. *This is noted as a potential further research topic, but it is doubtful whether the low level of confidence in future wind conditions would justify anything more than a 'what if' approach at present.*
10. Spatial and temporal analogues may be helpful in understanding the potential impacts on flood defence. For example, parts of the UK may have a flood regime more similar to areas in France or elsewhere. *'Type' events from the historical record, such as the Autumn 2000 flood or 1947 snowmelt can be simplistically linked to extreme seasonal conditions with a known change in frequency under future climate scenarios.*
11. Although not mentioned by any of the interviewees, it would be useful to have a discussion note on what can be done to predict climate change impacts on coastal morphology, eg cliff and beach recession and siltation. *This has been logged as a potential further research topic, but any impact calculations would be subject to great uncertainty.*

12. Joint probability calculations involve assessment of the combined probability of the simultaneous occurrence of two or more load variables, eg waves, water levels and river flow. Information on present and future dependence between key pairs of variables, for example surge, rainfall and/or waves would be useful. *Mapping of present-day dependences between several variable-pairs is the subject of recently commissioned work at HRW/CEH, and Sutherland and Wolf (2002) demonstrate the calculation of dependence for present and future scenarios: this is noted as a potential further research topic, but it is doubtful whether the low level of confidence in future scenario data would justify intensive analysis at present.*
13. Evaluation of the change in standard of service over the design life of a defence, (aspects other than climate change being equal) would provide a direct indication of the effects of climate change on the value of flood and coastal defences. *This seems a good idea, not routinely practised at present, and one that Defra might consider adopting as part of a standard assessment of existing and proposed defences.*
14. Consider social and environmental impacts, as well as economic impacts, and develop public awareness. *Agreed in principle, but it is difficult to incorporate 'soft' issues into a hard economic assessment, and the issues will be 'parked' for the moment for later consideration by Defra.*
15. Present a Defra Conference paper or similar on the use of the data and guidance. *Papers at the 2002 Defra Conference (Hawkes, Wade and Reynard, 2002) and at the 2002/03 CIWEM Winter meeting (Hawkes, Surendran and Richardson, 2003).*

## **2.7 Summary of main points**

The main point coming through the interviews was that users did not want discretion in quantifying and applying future climate change. They would prefer plausible, consistent straightforward guidelines, ideally in the form of contour maps of rainfall change, wave height change, sea level rise etc. It is interesting to note that the appropriate precautionary allowances presently adopted for future sea level rise (assume a rate of rise of 4 or 5 or 6mm/yr) and river flow (assume possible 20% increase) are the only commonly used future climate change allowances. The figures need not be predictions of what will actually happen, but where realistic predictions are not possible, there should be sensible contingency allowances, for example, assume that the value of a key variable might increase by as much as 20%.

There was a feeling that perhaps the climate change calculations should focus more on the *consequences* of change than they do at present, and that they should be considered in the context of the many other uncertainties involved. However, it was realised that this would be difficult without making the procedures too complicated for actual use.

Once established and accepted, apply the guidance consistently and don't change it unless really necessary.

### 3 UKCIP02 FUTURE CLIMATE SCENARIO COMPONENTS

#### 3.1 Climate models and scenarios

The UKCIP02 information is based on output from a nested climate modelling system run at the Hadley Centre. The global HadCM3 model is an improved Ocean Atmosphere General Circulation Model (GCM). It provides input to a 150km resolution Atmosphere Only global model, which in turn is used to drive the 50km resolution HadRM3 European Atmosphere Only model. This three-stage approach was used because the 150km model represents well the storm tracks over the North Atlantic, and because models cannot represent topographic effects at length scales less than the grid spacing. Regional climate models dynamically downscale GCM climate features while better representing the land topography.

For storm surges, needed as input to extreme sea level assessment in UKCIP02, the Hadley Centre used the 50km model winds and atmospheric pressure as input to the 30km resolution operational surge model developed by the Proudman Laboratory.

30-year time slices were run: 1961-1990 representing present-day conditions and 2071-2100 representing future conditions.

Post processing at the Tyndall Centre and the Climatic Research Unit, both at the University of East Anglia, then developed the source model data into structured scenarios using appropriate techniques such as scaling and temporal aggregation. The raw model data generally contain certain biases which are detected and adjusted during this processing, by comparison of the model with an observed baseline.

In 2000, the Inter-governmental Panel on Climate Change produced the IPCC Special Report on Emission Scenarios (SRES). SRES covers a total of forty future demographic, economic and technological ‘storylines’, of which the four representative scenarios listed in Table 1 are used in UKCIP02. It is important to recognise that none of the scenarios is more likely than any other; they are all plausible descriptions of socio-economic trends that could affect future emissions of greenhouse gases.

**Table 1 Description of four scenarios used in UKCIP02**

Scenario	Outline
A1: High Emissions	Very rapid economic growth, a global population that peaks in mid-21 <sup>st</sup> Century and thereafter declines, and the rapid introduction of new and efficient technologies. The scenario also envisages increased cultural and social interaction, with a convergence of regional per capita income.
A2: Medium-High Emissions	A very heterogeneous world, characterised by self-reliance and preservation of local identities. Population continues to grow but economic growth and technological change are slower than other storylines.
B1: Low Emissions	The same population dynamics as A1, but a transition toward service and information economies, with lower material consumption and widespread introduction of clean and efficient technologies.
B2: Medium-Low Emissions	A world with lower population growth than A2, accompanied by intermediate levels of economic development, with less rapid and more diverse technological change than in B1 and A1.

Results for the 2020s and the 2050s are inferred in UKCIP02 from the source data for the 1961-1990 and 2071-2100 periods by an interpolation method known as ‘pattern scaling’. (The interpolation is based on temperature change rather than passage of time.) Additional 5km resolution data are available for some climate variables from the UKCIP web-site (<http://www.ukcip.org.uk/scenarios>) derived from the source 50km resolution data by interpolation rather than by recovering new information.

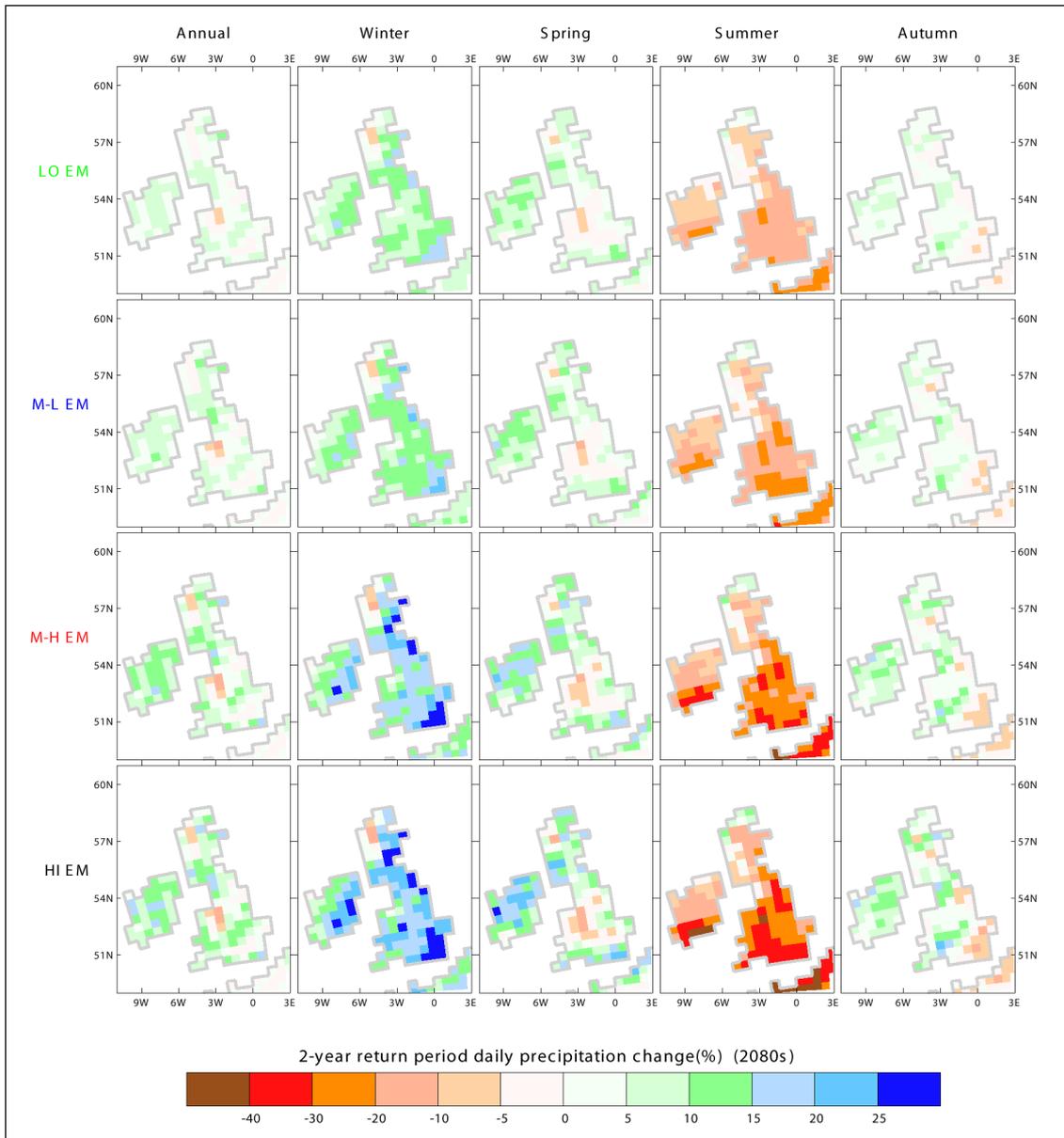
Variables saved directly from the Hadley Centre model runs include sea level rise, wind speed and direction, precipitation and soil moisture. Derived variables include surges and ocean currents, but wave conditions and river flows will need to be the subject of further modelling and interpretation.

Users should be aware that the UKCIP02 scenarios are the realisation of a single GCM (HadCM3). As acknowledged in UKCIP02, uncertainties in the design or choice of climate models translate into uncertainties in regional climate scenarios. In other words, a different GCM (with different climate sensitivity and parameterisations) would almost certainly produce a different set of scenarios for the UK given the same SRES emission scenarios. The results are therefore described in UKCIP02 not as ‘predictions’ but as scenarios.

### **3.2 Rainfall**

UKCIP02 indicates that Winters will become wetter and Summers will become drier, the changes being more marked in the south and east of the UK. Separate results are given for daily and seasonally averaged rainfall at the ‘medium/high’ level of relative confidence, and there are maps of changes in the numbers of days over certain rainfall thresholds, but no information is given for different durations of rainfall. Heavy Winter precipitation (and by implication high river flows) will become more frequent. By the 2080s, the 2-year return period Winter daily precipitation may be 5-20% higher than at present: Figure 1 shows the seasonal and regional variations for the four emissions scenarios considered. (The UKCIP web-site provides similar maps for 5, 10 and 20 year return periods, but the pattern and magnitude of changes are similar).

In a marked departure from the UKCIP98 scenarios, average Autumn rainfall will decrease in England and Wales by up to 20% by the 2080s (High Emissions Scenario). UKCIP02 also indicates that the inter-annual variation of rainfall may increase in Winter and Autumn, remain stable in Spring and decrease in Summer. Overall, the changing rainfall pattern suggests a delayed start to the ‘flooding season’ in Autumn, followed by periods of more intense rainfall and high flood risk in Winter, but a reduced risk of flooding in Spring and Summer. The impact of UKCIP02 on peak flow are the subject of another Agency/Defra study that will resolve the changing seasonal patterns of flood risks.

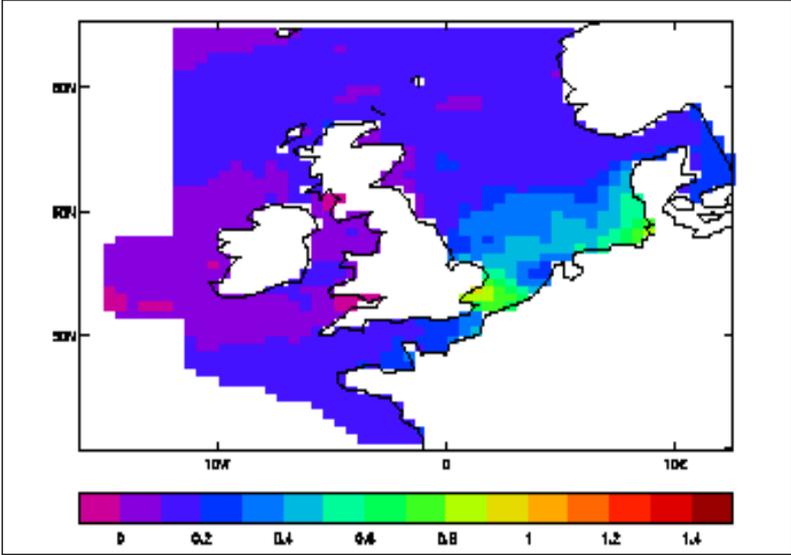


**Figure 1 Percentage change in the 2-year return period daily precipitation between now and the 2080s (reproduced from UKCIP02 showing increases of up to 25% in Winter and decreases of up to 30% in Summer)**

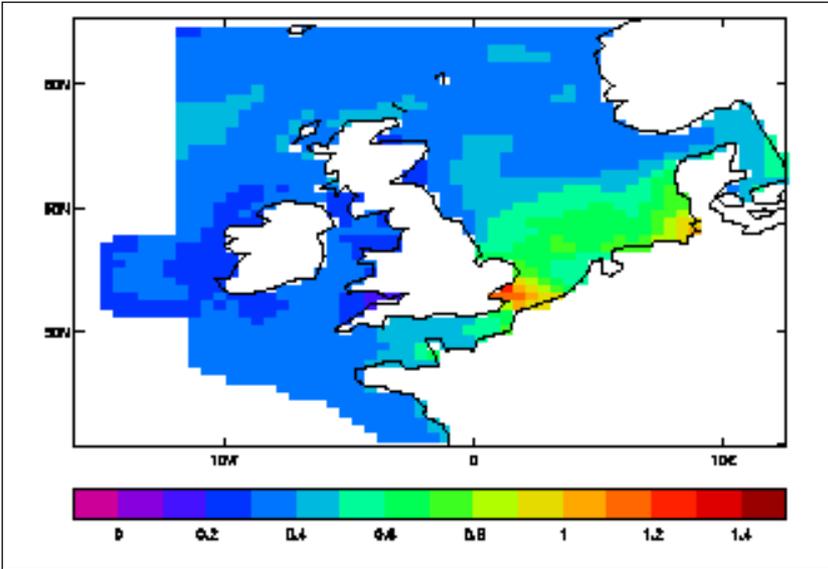
### 3.3 Sea level

UKCIP02 provides sea level rise information for the 2020s, 2050s and 2080s for different parts of the country. It indicates that relative sea level will continue to rise around most of the UK. Predictions of global mean sea level rise by the 2080s have a wide range of possible values at the ‘medium’ level of relative confidence in the accuracy of the figures. The mean level may be between 2cm below and 58cm above the current level in western Scotland, and between 26cm and 86cm above the current level in south-east England by the 2080s. The increase in extreme sea levels, taking account of surge as well as relative mean sea level rise, will follow a slightly different pattern, but will again be higher in the south-east than in the north-west. Figures 2a-2c show the increase in the 50-year return period sea level, from the

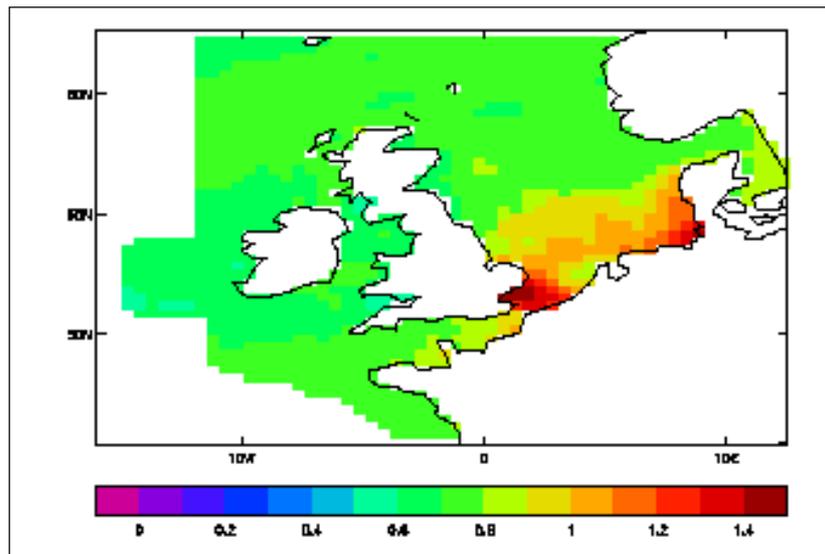
model results for the Low, Medium-High and High Emissions scenarios, given at the 'medium/low' level of relative confidence.



**Figure 2a** Increase in the 50-year return period sea level between now and the 2080s under the Low Emissions scenario (reproduced from UKCIP02 showing increases of around 0.2m for most of the UK but up to 0.8m in the Thames estuary)



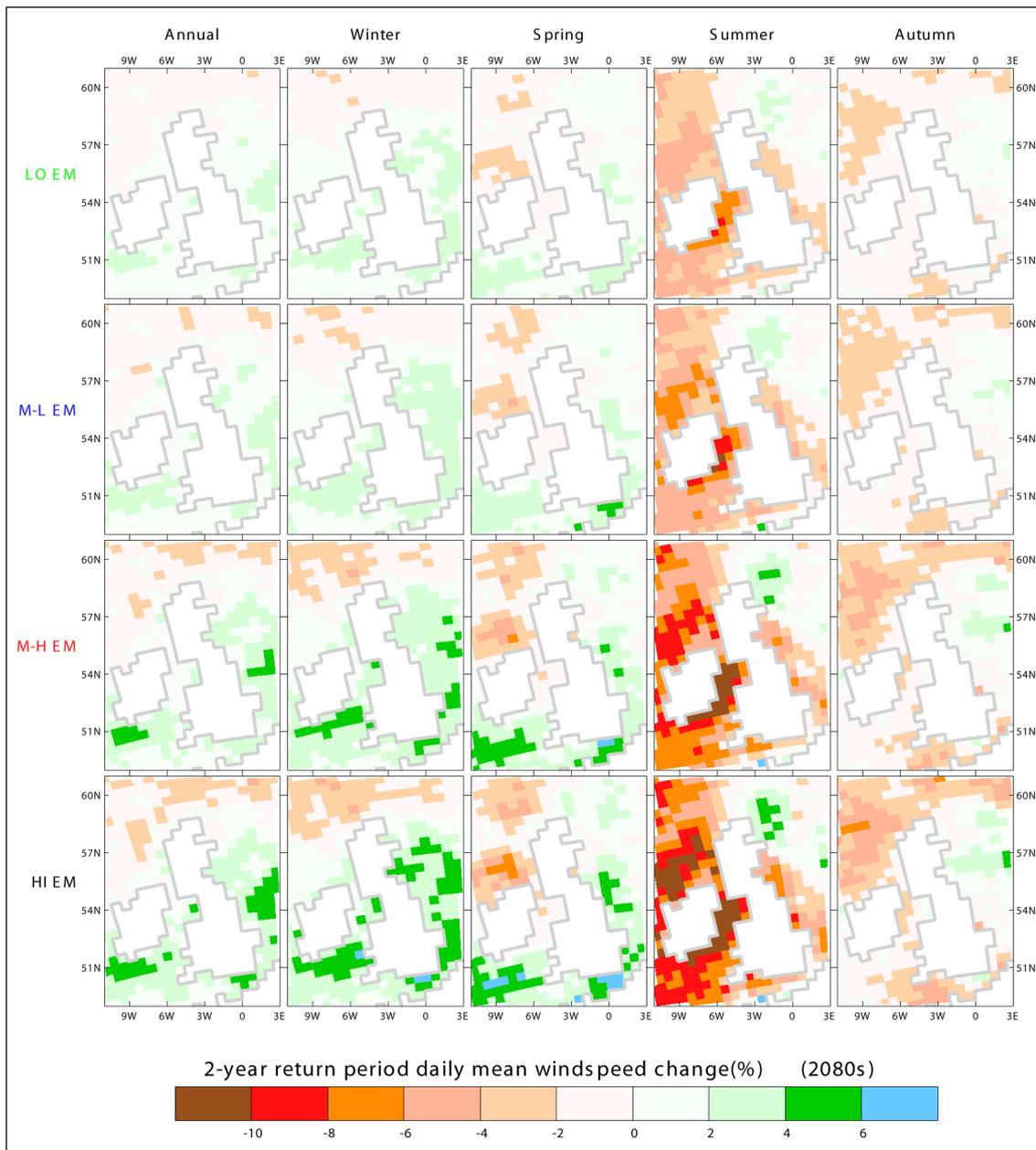
**Figure 2b** Increase in the 50-year return period sea level between now and the 2080s under the Medium-High Emissions scenario (reproduced from UKCIP02 showing increases of around 0.4m for most of the UK but up to 1.2m in the Thames estuary)



**Figure 2c Increase in the 50-year return period sea level between now and the 2080s under the High Emissions scenario (reproduced from UKCIP02 showing increases of around 0.7m for most of the UK but up to 1.5m in the Thames estuary)**

### 3.4 Wind speed

Wind speeds are stored as mean daily values during the climate model runs, although 6-hourly records could be made available for specialist use in wave and surge modelling. UKCIP02 results for future wind conditions carry a low level of confidence. Spring and Autumn conditions appear to be little changed between now and the 2080s, although Winter winds (and by implication high waves) in southern Britain may increase slightly. Figure 3 illustrates the seasonal and regional changes in the 2-year return period daily averaged wind speed which may occur, with decreases of up to about 7% in the Summer and increases of up to about 6% in the Winter. (The UKCIP web-site provides similar maps for 5, 10 and 20 year return periods, but the pattern and magnitude of changes are similar). UKCIP02 notes that changes in offshore wave climate and wind direction are not well quantified and no estimates are given.



**Figure 3 Percentage change in the 2-year return period daily averaged wind speed between now and the 2080s (reproduced from UKCIP02 showing increases of up to about 6% in Winter and decreases of up to about 7% in Summer)**

### 3.5 Soil moisture

Change in soil moisture is addressed explicitly in UKCIP02, on a seasonal basis, at the ‘medium/high’ level of relative confidence. This information could be incorporated into flood modelling, but catchment scale rainfall-runoff models based on UKCIP02 rainfall and evapotranspiration scenarios are likely to provide more robust estimates of soil moisture than the Regional Climate Model. Unfortunately the UKCIP02 scenarios do not include Potential Evapotranspiration (PET) estimates but these can be derived (with due care and a number of assumptions) based on changes in temperatures, windspeed and solar radiation that are provided in the data set.

### **3.6 Uncertainties**

Uncertainty, and how it varies through the scenarios, is acknowledged and discussed as an issue in UKCIP02. Information is given on uncertainties due to choice of assumptions, model, scenario and spatial resolution, but this information requires some interpretation to be useful in flood and coastal defence studies.

## 4 RECOMMENDATIONS

There was little difference between the views of different types of user addressing similar types of activity. In other words, practitioners, regulators, local authorities and developers had broadly similar requirements for climate change information. The recommendations in this report are therefore developed in note form using a scientific classification: rivers, coastal, impacts etc. The content of Section 4.1 and parts of Section 4.2 are expanded upon in user manual format in the Guidance for Users (Environment Agency / Defra, 2003). The content of Section 4.3 is expanded upon in the form of outline research proposals in Appendix 2.

### 4.1 Which user needs can already be addressed?

1. Change in mean sea level is addressed explicitly in UKCIP02. Predictions of global mean sea level rise by the 2080s have a wide range of possible values at the 'Medium' level of relative confidence. The issue of relative mean sea level rise around the UK, including local differences due to land movement, is also addressed directly. Change in storm surge, and its impact on extreme water levels is also discussed, but results are at the 'Low' level of relative confidence.
2. Change in rainfall is addressed explicitly in UKCIP02, with separate results for Winter and Summer, and for daily and seasonal averages, at a 'Medium to High' level of relative confidence. This information could be used directly in flood and coastal defence studies, but would benefit from some interpretation for different durations of rainfall.
3. Change in wind speed over water is addressed explicitly in UKCIP02, but only in the form of daily mean wind speeds, without an estimated level of relative confidence (therefore assumed to be low). These are not ideal figures for direct use in flood and coastal defence studies, but provide an estimate of the likely corresponding change in wave height. UKCIP02 notes that changes in offshore wave climate and wind direction are not well quantified and no estimates are given.
4. Change in soil moisture is addressed explicitly in UKCIP02, on a seasonal basis at a 'Medium to High' level of relative confidence. This information could be incorporated into flood modelling.
5. Uncertainties, and how they vary through the scenarios, are acknowledged as issues in UKCIP02. Information is given on uncertainties due to choice of assumptions, model, scenario and spatial resolution, but this information requires some interpretation to be useful in flood and coastal defence studies.
6. Change in seasonality is addressed explicitly in UKCIP02 wherever direct scenario results are given.
7. Some information on extremes is given in UKCIP02, including the 50-year return period sea level and the 2-year return period daily averaged wind speed and rainfall. However, to be useful in flood risk assessment, it would be necessary to assume that the wind speed and rainfall results can be extended to other return periods and durations.

8. Methods already exist within the flood and coastal defence community for evaluation of costs, benefits, standards of service, risks and potential losses, and for determination of investment decisions. These calculations can be re-visited for future conditions, incorporating any appropriate allowances for climate change. Uncertainties in source data, present-day predictions and climate change allowances could be incorporated and propagated through the calculations as part of a developing risk-based approach to flood analysis.

#### **4.2 Which user needs require further research?**

This section contains a wish list of users' ideas, sorted in approximate in order of priority, but without regard for practicality. It is intended to complement the list of ideas in Section 4.1 which can already be addressed directly by UKCIP02. Some of the ideas below could be addressed by less direct use of UKCIP02 information, whilst others may need further research or may be impractical at the present level of confidence in future climate modelling.

1. Potential change in river flow is currently addressed by a precautionary allowance approved by Defra of plus 20% on volume (towards the top end of values predicted in individual site-specific studies). For example, results from a number of studies suggest that changes in 10-year and 50-year flood flows on the Thames at Kingston and Teddington are likely to be in the range of 3-16% higher across the full range of climate scenarios. Refinement of the 20% allowance could be achieved by continued development of flood estimation techniques driven by rainfall predictions, rather than by mapping of future river flows in which it would be difficult to incorporate the concepts of catchment wetness, seasonality and duration. This might be done using continuous simulation or updates to the Flood Studies Report rainfall-runoff model.
2. Potential change in wave conditions is currently addressed in a study-specific manner, if at all, and there is no existing national allowance for wave climate change, except in regard to the potential increase in breaking-limited nearshore wave heights as water depth changes. Large scale wave modelling driven by time series wind conditions could be undertaken, or it could be assumed that offshore wave heights will change proportionally to any change in daily mean wind speeds, but the low confidence in future wind predictions limits the value of either of these approaches.
3. Different users are interested in changes in rainfall frequency for specific durations related to catchment critical durations or shorter time periods for urban drainage calculations. Results are needed as a 'family' of depth-duration-frequency curves with probabilities (on the x-axis) plotted against rainfall depths for certain durations either in mm per day (or average mm per hour) or a change factor from the 1961-1990 control climate. An alternative form of presentation would be a set of spatial grids providing similar output to the contour maps reported in Jones and Reid (2001).
4. Change in catchment wetness and groundwater levels is addressed in UKCIP02 but requires further interpretation for use in flood studies (possibly by incorporation within Item 1 above). Although UKCIP02 reports changes in soil moisture with a 'Medium to High' level of confidence it is unlikely that these estimates could be used directly in flood studies. Further work is required to compare these coarse 50km square results to modelled average catchment wetness or soil moisture contents. There is too much

variation between soils within the 50km grid squares for the UKCIP02 estimates to be directly useful but it may be possible to interpolate onto a finer grid taking account of soil type variation within the grid square.

5. Predicted change in costs, benefits, standards of service, risks, potential losses, investment decisions etc can already be re-visited for future conditions, but it would be helpful to have guidelines as to what are appropriate allowances, or which parameters need to be considered, in different situations.
6. Uncertainties and potential change in extremes (of some meteorological and derived variables) are addressed in UKCIP02 but further work is required to produce all of the variables and parameters needed (see Section 4.3) for flood and coastal defence decisions.
7. Potential change in storm frequency, intensity, tracking and sequencing would require further modelling, probably at a finer spatial resolution, but possibly this is not justified until confidence in future wind predictions is higher. The Hadley Centre and the Climatic Research Unit are presently doing research on this issue.
8. Potential change in dependence and joint probability can be calculated from time series data on the variables of interest, but meaningful predictions probably cannot be done until confidence in future wind and surge conditions increases. This could be linked to Item 7 above, as any significant change in dependence is likely to be associated with a corresponding change in storm tracking.

### **4.3 Research requirements**

This section lists, in approximate order of importance, those topics which are worthy of further research in support of appropriate usage of UKCIP02 climate change scenario information in flood and coastal defence work. An outline research proposal, for joint Defra / Environment Agency R&D work, is given in Appendix 2 for each of Items 1-6.

Note: Since preparation of the research ideas in Sections 4.3 and 4.4, some of the topics have been taken forward as formal proposals or as ongoing research projects. They have not been removed from the 'research requirements' or 'other research ideas' lists, but where applicable, a note in italics on proposals or projects is appended.

1. Continuous flow simulation for different catchment scales and climate scenarios, to convert future rainfall conditions to river flows, and refine the present 20% allowance for future rainfall and consequent flow river flow. Select a variety of hydrological regions and in each of these a number of catchments of different sizes to be used in modelling and analysis approaches consistent with the present FEH. Convert predictions of changes in river flow into appropriate guidance to flow modellers, either as simple allowances or alternative inputs to FEH. *A project along these lines has recently commenced at CEH Wallingford under the Agency / Defra REUU programme. In a related project, led by the Hadley Centre, CEH Wallingford is involved in linking a catchment model to the Hadley Centre regional climate model, possibly leading to improved predictions of river flow.*
2. Total sea level rise (including changes in mean sea level, tidal range and surges) is a pressing issue, particularly in view of UKCIP02 suggesting a larger increase in extreme

sea level for Thames and Anglian than had previously been expected. Hopefully, confidence in the results can be increased to the extent that best estimate predictions of extreme sea level rise can be made for different return periods and periods into the future. This would probably involve POL re-running continuous simulations using the existing continental shelf models, taking input from alternative global climate models to see the range of results that can be obtained. Also, the Hadley Centre could re-process existing POL simulations based on the UKCIP02 scenarios to obtain additional parameters. The main results would be presented as maps of changed 'total' water level around the UK, particularly for extreme high (and low) levels, for a range of scenarios and climate models. *This topic forms part of a larger proposal on environmental extremes made by HR Wallingford and the Proudman Laboratory to the Agency / Defra REUU programme.*

3. Wave climate predictions, probably using continuous simulation, producing climates, extremes and information on direction. This could be done using the UKMO 12km model, with additional local modelling where resolution needed. If possible, map regional changes (or at least realistic allowances) in wave height and direction. More detailed results would be presented as statistical summaries, in the form of wave roses, percentage exceedence tables and estimates of large wave heights (by season and/or direction). *This topic forms part of a larger proposal on environmental extremes made by HR Wallingford and the Proudman Laboratory to the Agency / Defra REUU programme. It also forms part of a larger proposal prepared by the Hadley Centre for inclusion in its climate change programme.*
4. Provide advice and methods for converting information on changing waves and water levels (Items 2 and 3 above) to assessment of the likely adequacy, structural stability and standard of service of existing defences. The combined HR Wallingford and POL Coastal Defence Vulnerability 2075 project (Sutherland and Wolf, 2002) was a pilot for this kind of work (using German ECHAM climate data) and methods could be re-applied for additional sites using one or more UKCIP02 scenarios. Results would include indications of likely changes in the principal design parameters, and how to incorporate such changes in the design of coastal defences now.
5. Provide information on changes in high-intensity rainfall events (durations of 15 to 60 minutes) to be used in design of drainage systems, particularly for paved areas (roads, roofs, town centres). It is hoped that this could be achieved by downscaling future rainfall predictions using weather generation models, but it may be better to run a feasibility study before embarking on the full study. Results would be expressed in terms of revised statistics and maps of intense rainfall events. *This topic forms part of a larger proposal on environmental extremes made by HR Wallingford and the Proudman Laboratory to the Agency / Defra REUU programme. There is also a proposal by UKCIP to do this within the EPSRC/UKCIP Built Environment programme.*
6. Advise on potential climate change impacts on coastal morphology, eg cliff recession rates, beach recession, shore platform evolution, sandbank and estuary changes. This would be addressed using climate change information in simple predictive models, eg longshore drift rate calculations, empirical beach profile predictors. Because of the uncertainties involved (even in present-day morphological modelling) results might best be presented in the form of a discussion document rather than as predictions of future morphological change.

#### 4.4 Other research ideas

This section lists other ideas that might be re-visited at a later date, that are either not useful at the present level of confidence in the climate change scenarios or that are too far removed from the main aim of facilitating take-up of UKCIP02.

1. The dependence between key pairs of variables is important in assessing flood risk, for example waves and water levels for sea defences, and flows and water levels for river defences. (HR Wallingford has an ongoing project to map dependence around the UK for several variable-pairs, based on long-term measured data). If reliable predictions were available for the simultaneous occurrence of two such variables under different climate scenarios, then any change in dependence could be calculated. However, it is hard to see how future climate models could demonstrate changes in dependence, unless driven by a dramatic change in weather patterns. This topic may be worth a feasibility level study to see whether anything could be done consistent with the present level of confidence in the UKCIP02 scenarios.
2. There may be more that could be done in the area of catchment wetness, groundwater levels and rainfall intensities for different durations, beyond what is already covered by Section 4.3 Items 1 and 5. It should be possible to derive at least plausible contingency allowances for catchment wetness and groundwater levels, and for rainfall or flow changes for different areas and durations, but these may emerge from any work done under Items 1 and 5. It may also be possible to look at changing year to year variability in rainfall. With a more variable climate there would be a larger difference in rainfall (and flows) between extreme events and average conditions. Rainfall and flow growth curves would then become steeper rather than increase by the same percentage across a full range of return periods.
3. The spatial coherence of storms may not be well represented in a 50km resolution model, and storm tracking and local impact on flood risk may not be apparent from regional daily mean or annual change information. It may be worth running finer gridded models in critical areas, initially to test the suitability of UKCIP02 for use in locally complex areas.
4. The potential benefit of a programme of verification of UKCIP02 scenarios for flood risk analysis could be considered. The general validity of UKCIP02 (and the underlying General Circulation and Regional Climate Models) could be assessed by running the same models in hindcasting or forecasting mode. For example, given known boundary forcing, could the dynamical downscaling capture surface variables of interest to hydrologists under present climate conditions? This form of experiment would enable verification of the models and quantification of uncertainties with respect to critical flood indices. *The Hadley Centre has proposed work along these lines.*
5. Appropriate take-up of UKCIP02 could be monitored in an organised way. There could be post-project appraisal across the realm of climate change and flood impacts. The extent to which stakeholders are incorporating the new uncertainties in project planning and design remains unclear. An archive of meta-data containing project descriptions, findings and actions would be a useful resource, ensuring that knowledge gained through the application of the UKCIP02 scenarios builds on earlier work and is effectively assimilated by future programmes.

6. Changing climate may introduce a need for new or more precise event definitions. Further guidance is required on the use of return periods and probabilities in non-stationary climate conditions. These could be presented as the probabilities associated with the climate of a future 30-year period (2020's, 2050's, 2080's) or could combine all the historical data with future flood peaks to derive return periods. A related issue is whether it is better to use flood peaks or flood volumes. Some of the regional work completed on the Autumn 2001 floods dodged this issue, presenting return periods for individual flood peaks within the Autumn without either looking at volumes or attempting to estimate the combined probability of a series of events. The nature of flooding may change in the future and different approaches may be needed.

## 5 REFERENCES

Defra / Environment Agency (2002). Risk, performance and uncertainty in flood and coastal defence: A review. Defra / Agency Report No FD2302/TR1 (also referenced as HR Report SR 587).

Environment Agency (2000). Climate change risk and uncertainty: Draft decision framework. Agency Report No 21.

Environment Agency / Defra (2003). UK Climate Impacts Programme 2002 Climate Change Scenarios: Implementation for Flood and Coastal Defence: Guidance for users. Environment Agency Report W5B-029/TR (also referenced as HR Report SR 613).

P Hawkes, S Wade and N Reynard (2002). UKCIP02 climate change scenarios: Implementation for flood and coastal defence. Defra Conference of River and Coastal Engineers, Keele.

P Hawkes, S Surendran and D Richardson (2003). Use of UKCIP02 climate change scenarios in flood and coastal defence. CIWEM Rivers and Coastal Group Winter Meeting 2002/03.

P Jones and P Reid (2001). Assessing future changes in extreme precipitation over Britain using regional climate model integrations. International Journal of Climatology.

MAFF (now Defra, 1999). Flood and coastal defence project appraisal guidance: Volume 3: Economic appraisal. MAFF Publication PB 4650.

MAFF (now Defra, 2000). Flood and coastal defence appraisal guidance: Volume 4: Approaches to risk. MAFF Publication PB 4907.

J Sutherland and J Wolf (2002). Coastal defence vulnerability 2075. HR Wallingford Report SR 590.

United Kingdom Climate Impacts Programme (2002a). Climate change scenarios for the United Kingdom: The UKCIP02 briefing report. Available from <http://www.ukcip.org.uk/scenarios>.

United Kingdom Climate Impacts Programme (2002b). Climate change scenarios for the United Kingdom: The UKCIP02 scientific report. Available from <http://www.ukcip.org.uk/scenarios>.

UKCIP / Environment Agency (2002). Guidance on handling risk and uncertainty in decision making for climate change.



# APPENDICES



## Appendix 1 Telephone interview logs

Name	Organisation	Coastal / Rivers / Impacts	Regulation / Practice / Research
Mark Hagger	Environment Agency	Rivers, Coastal	Regulation, (Practice)
David Crowson	Environment Agency	Rivers	Regulation
Pat Steward	Environment Agency	Impacts	Regulation
Ian Meadowcroft	Environment Agency	Impacts, (Rivers), (Coastal)	Research, Project Board
Jim Haywood	Environment Agency	Impacts, Rivers	Research, Practice
David Richardson	Defra	Impacts, Rivers, Coastal	Regulation, Research, Project Board
Steven Jenkinson	Defra	Coastal, Impacts	Regulation
Peter Jones	National Assembly for Wales	Rivers, Coastal, (Impacts)	Regulation
David Noble	Association of Drainage Authorities	Impacts, Rivers, (Coastal)	Practice, Regulation
Lindsey Frost	Lewes District Council	Impacts	Regulation
Ted Edwards	Canterbury City Council	Coastal, (Rivers)	Practice
Chris Wotherspoon	Babtie Group	Rivers, Coastal	Practice
Duncan Faulkner and Simon Waller	Jeremy Benn Associates	Rivers, (Coastal)	Practice, (Research)

**UKCIP02 CLIMATE CHANGE SCENARIOS: IMPLEMENTATION FOR FLOOD AND COASTAL DEFENCE: Record of telephone interview on the use of future climate change information in flood and coastal defence studies**

**Area of special interest:**                      **The National Capital Programme for improving flood defence**

*Which aspects of your work require consideration of future climate change?*

The most important aspect is the impacts on flood defence schemes and the quantification of impacts with regard to the economic viability of schemes as calculated through the PAG.

Both fluvial and coastal climate change impacts should be considered.

*How do you deal with them at present?*

Currently the Defra guidance is used to take account of sea level rise but guidance is also needed in order to understand the sensitivity of rivers flows and storminess to a changing climate.

The current approach used for rivers is 1 in 100 year + 20% river volume.

*Would you prefer to deal with them differently? Do you use UKCIP98 data? What information formats do/would you prefer?*

As far as I know nobody uses the UKCIP 1998 data at present. This is due to a lack of (i) time and (ii) national guidance on how the data should be used. A similar level of guidance is required to the Defra SLR figures.

Any guidance relating to river flows should sit well with FEH approaches. For example, if the climate scenarios suggest shorter, sharper storms then this should be fed into the storm profile shape used to estimate flood hydrographs.

Similarly, changes in storminess also need to fit in with standard surge analysis approaches. The impacts will vary along the coast.

Any information provided from UKCIP02 must be as unambiguous as possible. Need to avoid the situation where lots of different figures are quoted and the potential climate impacts are misunderstood.

<<*Post note – previous analysis has suggested that Winter storms will become more intense, e.g. a doubling of the 1 in 1 year daily rainfall. However storm profiles shouldn't be changed without also considering changes catchment wetness (CWI) and the proportion of the catchment that is "wet"(PROPWET)*>>

*Do you have any additional information requirement or research need?*

Good rainfall outputs are the top priority but would also like information of changing CWI.

Rainfall durations of between 1 and 12 hours are of particular interest in the NW due to the rapid response of many of their rivers that are much shorter than the national average.

*What would you put on your wish list (whether practical or not) and which would be top priority?*

Need to have guidance on the most likely scenario to use for assessing climate impacts a.k.a the existing Defra guidance on Sea Level Rise.

*Additional comments*

Would like to see more consultants involved.

**UKCIP02 CLIMATE CHANGE SCENARIOS: IMPLEMENTATION FOR FLOOD AND COASTAL DEFENCE: Record of telephone interview on the use of future climate change information in flood and coastal defence studies**

**Area of special interest:**                      **Development control**

*Which aspects of your work require consideration of future climate change?*

- Land drainage consents
- New developments allocation of land for development
- Flood defence design for developments

*How do you deal with them at present?*

- Requirement on developers – PPG25 App F using FEH (25-30% increase in  $Q_{100}$ )
- Take 20% increase in rainfall or flow - national policy to increase by this factor

Flood resistant design if in a ring-defended area

*Would you prefer to deal with them differently?*

- Anything which makes job streamlined and nationally consistent would be of benefit
- Agreed national methodology

*Do you use UKCIP98 data?*

- No but some consultants have used on developers' behalf – not often

*What information formats do/would you prefer?*

- No preference – make it easy to use

*Do you know of any specific faults, difficulties, uncertainties, lack of data, situations not well dealt with at present?*

- No because no direct use – as a regulator, not best placed to comment.
- Try a consultant.

*Do you have any additional information requirement or research need?*

No

*What would you put on your wish list (whether practical or not) and which would be top priority\*\*?*

- Ease of access to data – internet – CD
- Simple format eg in a spreadsheet
- Agreed national methods for evaluation\*\*
- Automated through hydrological model to flow
- Idiot-proof access
- Available CPD for consultants
- Defra conference paper on the use of the data

**UKCIP02 CLIMATE CHANGE SCENARIOS: IMPLEMENTATION FOR FLOOD AND COASTAL DEFENCE: Record of telephone interview on the use of future climate change information in flood and coastal defence studies**

**Area of special interest:** Promoting all areas of the Agency's work; a major task is to influence people

*Which aspects of your work require consideration of future climate change?*

- Development and flood risks
- Design and construction
- PPG25 Risks Assessments

I am involved in promoting PPG25 and sustainable construction. My sources of climate change information are national reports and the regional scoping study report on climate change impacts.

*How do you deal with them at present?*

Simply promote an awareness of possible climate change impacts through my work. I am not involved in technical/engineering calculations that require specific use of climate data.

*Would you prefer to deal with them differently? Do you use UKCIP98 data? What information formats do/would you prefer?*

There is a lack of understanding of climate change impacts among developers and other groups. There is a need for meaningful practical advice on ways of dealing with climate change. Appropriate advice needs to be targeted at the national, regional and local levels. The economic and social impacts of climate change and flooding need to be considered not just the environmental impacts.

Need to refer to the DTLR guidance on climate change and planning decisions.

<<Post meeting note - Changes in flood volumes need to be translated into social and economic impacts based on existing or new economic approaches>>

*Do you know of any specific faults, difficulties, uncertainties, lack of data, situations not well dealt with at present?*

Yes, but many problems are due to the nature of the planning system. The Agency apply the precautionary principle but to refuse an application there needs to be a demonstrable impact of development on the environment. With climate change the precautionary principle might encourage the use of the most extreme climate scenarios but the impacts are hard to prove.

*Do you have any additional information requirement or research need?*

Require agreement across the board on what the climate scenarios mean and what the Agency and planners should be doing in response to the scenarios.

*What would you put on your wish list (whether practical or not) and which would be top priority?*

- A set of agreed actions on how to account for climate change
- The MAFF guidance for SLR is at an appropriate level of detail

**UKCIP02 CLIMATE CHANGE SCENARIOS: IMPLEMENTATION FOR FLOOD AND COASTAL DEFENCE: Record of telephone interview on the use of future climate change information in flood and coastal defence studies**

**Area of special interest: Risk research**

*Which aspects of your work require consideration of future climate change?*

One aspect is developing an integrated framework management of flood risk, accounting for:

- a range of flood management actions;
- a range of future 'scenarios' including climate;
- uncertainties made explicit - whether expressed as probability distributions, ranges, etc;
- recognition of flood risk management within a holistic system of environmental, economic, social, political and engineering pressures and opportunities.

This will require a consistent clear view of climate change impacts. Different 'risk managers' must have access to and make use of the same basic information. Consistency is very important. This doesn't necessarily mean the same allowances. Different decision-makers may however use different 'allowances' depending on eg different degrees of precaution.

Second main aspect is the more 'holistic' view exemplified by the approach to risk which begins with a broad examination and identification of all significant hazards. In terms of climate change this means assessing the 'obvious' such as daily rainfall and SLR but also the not so obvious, such as changes in antecedent conditions, and storm sequences.

Thirdly, in terms of operational support, climate parameters are a fundamental component of planning and decision-making. These mainly focus on assessments required to implement current guidance BUT standard information on even the basic climate parameters is very limited.

*How do you deal with them at the moment?*

Mainly published guidance / allowances eg in the Defra Project Appraisal Guidance series.

Some limited R&D into specific issues eg Coastal Defence Vulnerability 2075.

*Would you prefer to deal with them differently?*

Yes - I have concerns that

- i. Current guidance is not sufficiently flexible. There is a tendency to take information developed for a very specific case and extrapolate it beyond its applicability.
- ii. Current information rarely considers uncertainty in any rigorous transparent way, except for projecting a range of scenarios to illustrate possible futures.
- iii. We don't seem to have a systematic methodology for building climate change into our flood risk management decisions. This is I think a key point. How about moving towards a GIS of climate change meta-information and information?

[Example – the Environment Agency's development control uses IFPMs. These could be 'adjusted' for climate change but is this justified when they don't include the effects of defences? Climate change is one influence in flood risk but not the only one. Without climate change there would still be (sometimes devastating) floods.]

*Do you use UKCIP98 data?*

Not personally. I know of examples where researchers have preferred to use other climate scenarios due to limited spatial / temporal resolution of UKCIP98.

*What information formats would you prefer?*

This needs careful thought. UKCIP98 seems to be an awkward compromise. It doesn't fully satisfy the researcher wanting to take specific impacts / issues further, and neither does it really provide the policy maker / public with the easy-to-understand messages.

Firstly, I would suggest that the information includes a 'knowledge base' which:

- identifies potential user groups and their needs;
- outlines the degree to which the scenarios meets or doesn't meet these needs;
- outlines what further specific analysis/ research would be needed to meet the needs etc.

Secondly, some sort of 'instruction set' is needed to help users get the most from the scenarios (some of this may already be planned in the UKCIP02 Report) but examples include:

- how to deal with / combine these AND OTHER sets of climate scenarios;
- how to present and deal with uncertainties in decision-making (ref NCRAOA Framework, and SR 587);
- list of points of which to beware;
- known limitations and methods to work around.

Thirdly, I'd like to see us build up a set of case studies of good practice in using the new scenarios.

*Do you know of any specific faults, difficulties, uncertainties, lack of data, situations not well dealt with at present?*

Uncertainty - the current projection of four scenarios leaves many decision-makers high and dry, in the absence of a developed policy in each case (eg for a particular decision, take the Medium-High Emissions scenario). It is almost impossible to develop this type of policy in the absence of any information on the relative likelihoods of a range of outcome. Probability information would also directly support and be compatible with Defra and Agency stated moves towards risk-based decision-making.

Not dealt with well at present. Antecedent conditions especially ground water / soil moisture. How to integrate UKCIP scenarios with eg continuous simulation models.

Storm sequences, in some cases very important for beach volume / alignment.  
Wind direction / strength / duration.

Combining climate uncertainties with others eg uncertainties global SLR plus land movements.

Joint probability eg cross parameter (waves/ surge and surge/ river flow), or spatial dependence eg joint probability of high flows simultaneously in different catchments. Not sure if climate models are any good at resolving changes on correlation, but statistical work on joint probability show that eg structural failure probability can be very sensitive to changes on correlation.

*Do you have any additional information requirement or research need?*

See above.

*What would you put on your wish list (practical or not) and which would be your top priority?*

Get the basics covered - clear national guidance on the main climate parameters, projected changes, and uncertainties. Question - is this covered by UKCIP02 or should additional information be introduced eg the recent flood record, other evidence?

Probabilistic information.

Systematic approach for accounting for climate change (ie a practical guide linking the UKCIP scenarios and NCRAOA/ UKCIP decision framework).

**UKCIP02 CLIMATE CHANGE SCENARIOS: IMPLEMENTATION FOR FLOOD AND COASTAL DEFENCE: Record of telephone interview on the use of future climate change information in flood and coastal defence studies**

**Area of special interest: Flood forecasting and warning**

*Which aspects of your work require consideration of future climate change?*

- Identification and extension of areas which need warning
- Improving public awareness

*How do you deal with them at present?*

- Broad-brush using previously published work
- Via the Environment Agency's Environmental Policy Centre for Risk and Forecasting

*Would you prefer to deal with them differently?*

- No – no gaps identified

*Do you use UKCIP98 data?*

- Not directly or in the NFWC currently
- Centre potentially in the future will use it

*What information formats do/would you prefer\*\*?*

- Electronic / CD / Internet\*\*

*Do you know of any specific faults, difficulties, uncertainties, lack of data, situations not well dealt with at present?*

- None known

*Do you have any additional information requirement or research need?*

- None at present

*What would you put on your wish list (whether practical or not) and which would be top priority\*\*?*

- Better quantification of extension of flood risk area
- Increase in frequency of flooding – especially over the next 5-10 years\*\*
- Secondary demographic and social impacts affecting flood plain occupancy, attitudes to flood warning and risk tolerance
- Changes in short-duration extremes which contribute to flash flooding

Speak also to Manager of Thames Barrier and Agency PM for national FFW modelling system strategy.

**UKCIP02 CLIMATE CHANGE SCENARIOS: IMPLEMENTATION FOR FLOOD AND COASTAL DEFENCE: Record of response (via email) on the use of future climate change information in flood and coastal defence studies**

**Area of special interest: Defra engineering policy**

*Which aspects of your work require consideration of future climate change?*

Climate change is recognised as a significant contributor to future uncertainty and potential increase in risks, particularly for flood risks.

*How do you deal with them at present?*

Keep under review the allowances that we recommend as a Department.

*Would you prefer to deal with them differently? Do you use UKCIP98 data? What information formats do/would you prefer?*

My view is that the provision of national allowances is the most efficient approach. By providing recommended allowances we can adopt a reasonable balance between unnecessary expenditure on measures to counter extreme predictions whilst taking a generally precautionary approach to likely future changes. It also avoids a significant amount of work, which would be needed if every scheme design had to look at potential future changes from first principles. The information provided in UKCIP was briefly reviewed to confirm that it did not warrant any change in the current recommended allowances.

The most useful form of future output would be maps of changes in flood flow occurrence in rivers, of future relative extreme sea levels around the coast and of future wave climates. However, the derivation of these requires not only model outputs, but also high-level policy input as to where reasonable limits should be drawn. It is probably better to adopt simple generalisations unless some confidence can be attached to predicted regional variations. Since investment decisions are being made that affect flood management over the next 50 years recommendations should not be changed frequently unless there is very good reason to do so as this can generate significant concern and unnecessary activity in revisiting decisions previously made.

*Do you know of any specific faults, difficulties, uncertainties, lack of data, situations not well dealt with at present?*

General uncertainty and lack of confidence in predictions of extremes - this can probably only be reduced by much greater understanding of the drivers for such events and the critical combinations of events at different time and spatial scales that lead to such extremes. Also probably need more consideration of socio-economic scenarios - these are a real minefield though if properly considered they can be helpful in putting other future uncertainties into perspective.

*Do you have any additional information requirement or research need?*

I am actively involved in development of the Defra /EA research programme.

*What would you put on your wish list (whether practical or not) and which would be top priority?*

As above.

**UKCIP02 CLIMATE CHANGE SCENARIOS: IMPLEMENTATION FOR FLOOD AND COASTAL DEFENCE: Record of telephone interview on the use of future climate change information in flood and coastal defence studies**

**Area of special interest: Scheme assessment, strategy studies**

*Which aspects of your work require consideration of future climate change?*

Scheme assessment and strategy studies: sea level rise is usually considered explicitly; wave climate change is usually limited to increased depth-limited wave heights following on from sea level rise.

*How do you deal with them at present?*

PAG3 gives explicit guidance on sea level rise. Defra is often asked for advice on application of sea level rise information. Other parameters not usually considered.

*Would you prefer to deal with them differently? Do you use UKCIP98 data? What information formats do/would you prefer?*

Do not use UKCIP98.

Would prefer to focus any calculations on the end result, for example choice of defence scheme, if any.

Prefer a relatively simple prescribed approach, such as presently used for sea level. Even if some aspects of future change are very uncertain, a realistic contingency allowance would be useful and would assist in a consistent approach to scheme appraisal. Do not want to prevent individual engineers using more accurate allowances for individual sites, but a simple default option would be useful (eg allow for the possibility of rainfall increasing by 20%); review frequently as better predictions become available.

Intelligible and easily applied.

*Do you know of any specific faults, difficulties, uncertainties, lack of data, situations not well dealt with at present?*

Tendency to treat climate change calculations as a directly useful exercise, rather than focussing on impacts on decisions.

Similarly, a tendency to spend a lot of time on detailed (if very uncertain) climate change calculations, without considering that other risks, uncertainties in data and process modelling, and natural variations may have greater impacts on decisions. [Comment relevant throughout the risk and uncertainty theme.]

*Do you have any additional information requirement or research need?*

Would like climate change maps from which information can be easily and reliably extracted, for example for sea level rise, wind direction change, and percentage change in wind speed, wave height and rainfall. Would probably need at least several areas around the country, so the expected 50km resolution of UKCIP02 would be adequate. Some changes may be in opposite directions in different parts of the country, some for the better and some for the worse.

*What would you put on your wish list (whether practical or not) and which would be top priority?*

**Reliable predictions of future climate change!**

Simple methods for applying them to aid consistent take-up.

**UKCIP02 CLIMATE CHANGE SCENARIOS: IMPLEMENTATION FOR FLOOD AND COASTAL DEFENCE: Record of telephone interview on the use of future climate change information in flood and coastal defence studies**

**Area of special interest: Flood and coastal defence management**

*Which aspects of your work require consideration of future climate change?*

- Fluvial and coastal aspects, especially vetting capital schemes –EA & LA flood defence, coastal defence and coastal protection
- Whatever scheme is proposed needs to work now and in the future
- Development of strategies and plans SMP and CFMPs
- Advising politicians on future policy

*How do you deal with them at present?*

Operating Authorities use Central Government PAG and Grant Mechanisms with CBA and detailed design including 5mm/yr sea level increase, e.g. include this in foundations. Rivers – frequency of flooding and design standards e.g. 50 year now is the same in 50 years time, no definitive guidance. View in Wales – more frequent floods but unquantified. Too early for PPG25 guidance on increased rainfall to feed through.

*Would you prefer to deal with them differently?*

- No comment on a different approach to PAG

*Do you use UKCIP98 data?*

- No real experience so far – too new in job
- Expects this to be used in the CFMPs
- Looking for operating authorities to do the appropriate impact modelling using CIP data and CFMP models

*What information formats do/would you prefer?*

- Ease of access and take up into modelling systems is important. Depends upon the operating authority. Need to make sure that formats are sufficiently flexible for no modification to be needed.

*Do you know of any specific faults, difficulties, uncertainties, lack of data, situations not well dealt with at present?*

- No faults, Uncertainties unquantified – hopefully will be reduced or identified. Engineering response is precautionary and pragmatic e.g. oversized foundations.

*Do you have any additional information requirement or research need?*

- Uncertainty in predictions

*What would you put on your wish list (whether practical or not) and which would be top priority?*

- Being able to say that the design standard X at this site will change to Y in 50 years time

**UKCIP02 CLIMATE CHANGE SCENARIOS: IMPLEMENTATION FOR FLOOD AND COASTAL DEFENCE: Record of telephone interview on the use of future climate change information in flood and coastal defence studies**

**Area of special interest: Flood protection and land drainage**

*Which aspects of your work require consideration of future climate change?*

- Everything! Internal Drainage Boards look after 1.2 M HA of land in total, 800Kha pumped into river coastal / tidal watercourses
- Sea level rise affects pumping. I surveyed IDBs several years ago and found a need for updated and new Pumping Stations because of SLR; I suggested 0.5m rise in level for planning.
- Systems in lowland areas depend upon storage – more volatile weather and heavier rainfall means more storage needed
- Development control – applications sent for comment - but no climate change input so far - just caution

*How do you deal with them at present?*

- 20% increase in rainfall used for design of new infrastructure
- SLR for new pumps to increase in heads take life as 50 years – 300mm
- realisation that climate change is likely because of recent rainfall incidents – need to keep systems working to their design capacity – do not reduce the maintenance standard. Frustrated by EA wilting under conservation pressures reducing maintenance and prejudicing drainage standards. Problem of designations and need to upgrade physical defences – eg on the Humber and the EA needing planning permission to repair Essex defences.

*Would you prefer to deal with them differently?*

- Want to make sensible allowances – cautious about being premature about changes since the IDB levy drainage rates – investments to meet realistic conditions rather than speculation.
- Put more weight to short term predictions rather than long term i.e. 15-30 year planning frame not 50-100 year.

*Do you use UKCIP98 data?*

- They are used by some drainage boards but not wide spread – only considered where there is a significant investment.

*What information formats do/would you prefer?*

- finer grid needed than UKCIP98.

*Do you know of any specific faults, difficulties, uncertainties, lack of data, situations not well dealt with at present?*

- Grid size

*Do you have any additional information requirement or research need?*

- One IDB has commissioned a study of how climate change will impact on their operations. This may lead to guidance and could be disseminated through ADA. The

IDB is looking at MSL and precipitation. Water Resources controlled by EA IDB will manage water whilst allowed by EA; so IDBs are not independent operators in drought.

*What would you put on your wish list (whether practical or not) and which would be top priority?*

- Level of “certainty” applied to the predictions
- We do not make fundamental decisions based on false predictions

**UKCIP02 CLIMATE CHANGE SCENARIOS: IMPLEMENTATION FOR FLOOD AND COASTAL DEFENCE: Record of telephone interview on the use of future climate change information in flood and coastal defence studies**

**Area of special interest:**      **Planning, building control, public health, environmental services, economic regeneration and emergency planning**

*Which aspects of your work require consideration of future climate change?*

Mainly flood and coastal defence, planning, building control. Also home energy conservation, tourism etc...

*How do you deal with them at present?*

For the design of defences, simply apply the Defra guidance, 6mm per year for the SE.

The District Council has adopted the "Nottingham Climate Change Declaration" that commits it to responding to climate change and supporting Defra's national strategy. The four main components of the declaration say that the LA is (i) to acknowledge that climate change is occurring, (ii) to seek to address climate change issues, (iii) to contribute to the UK programme and (iv) will plan, by 2002, for climate change with local communities.

<<Post note – interviewee provided a copy of the June 2000 booklet – "Community Leadership and Climate Change">>

*Would you prefer to deal with them differently? Do you use UKCIP98 data? What information formats do/would you prefer?*

Following the existing guidance would mean that this LA could not be provided with the standard of protection that would protect the town from the magnitude of flood that occurred in November 2000. A better consideration of climate change may alter the cost-benefit analysis, perhaps providing a scheme for the town with 1 in 100 year protection in 2050 and 1 in 200 protection now.

Consideration of climate impacts should form part of Catchment Flood Management Plans (CFMPs).

Very few local authorities have used UKCIP 1998 data. Some have contributed to regional scoping studies that have used the data.

National agencies must produce material on climate impacts that can be used at a local level. We require policy and practice guidance at all levels.

<<Post-note – The consideration of climate change, and the spatial variation of changes in particular, in PAG is very important. If the impacts are uniform across the UK then we wouldn't expect the consideration of climate change to affect the share of Defra funding across the country. However, if one region is likely to have greater impacts than another, would schemes be fast-tracked for funding?>>

*Do you have any additional information requirement or research need?*

Yes. Require outputs that can translate climate impacts to changes in the local rainfall field in terms of the changing frequency and spatial distribution of heavy rainfall events.

What is the probability of large storms “sitting” over one area or multiple storm tracks crossing the county?

We also need to know about possible changes in seasonal catchment conditions.

A top priority for us is to understand the interplay between storm surges and extreme rainfall – i.e. combined probability analysis and improved understanding of the dynamics of tidal-fluvial interaction.

*What would you put on your wish list (whether practical or not) and which would be top priority?*

- Clear guidance on the effect of climate scenarios on CFMPs
- Regular updates as new information becomes available
- Maps showing where the risks are
- Practical advice down to the local level not just influence on engineering and emergency planning communities
- Planners need to know what to ask for in a PPG25 risks assessment – in fact planners are not well trained in risks assessment approaches.

**UKCIP02 CLIMATE CHANGE SCENARIOS: IMPLEMENTATION FOR FLOOD AND COASTAL DEFENCE: Record of telephone interview on the use of future climate change information in flood and coastal defence studies**

**Area of special interest:      Local authority: coastal and fluvial**

*Which aspects of your work require consideration of future climate change?*

Coastal: sea level rise and consequent increase in depth-limited wave height.

Fluvial: rainfall, but perhaps this is about variability rather being than climate change issue.

*How do you deal with them at present?*

Accept the standard Defra 6mm/yr for this area (and consequent effect on depth-limited waves).

Use standard rainfall predictions but these seem poor at present.

*Would you prefer to deal with them differently? Do you use UKCIP98 data? What information formats do/would you prefer?*

Do not use UKCIP98.

Would like to be provided with plausible and easy-to-apply rules for sea level rise, rainfall increase and wave height change, published by acknowledged researchers (HRW/CEH/POL logos) and clearly supported by regulatory authorities (Defra /Agency logos). Prefer clear and prescribed advice on how and what to do, even if figures are contingencies rather than predictions.

Don't want discretion for in-house work, and would like to be *told*, for example, to allow for increased height of depth-limited waves.

*Do you know of any specific faults, difficulties, uncertainties, lack of data, situations not well dealt with at present?*

Based on standard present-day local rainfall predictions, there have been four 15-year return period events in the last 18 months: is this climate change, bad luck, or wrong predictions? [This is a site-specific issue outside the scope of the present study, but is an interesting observation.]

*Do you have any additional information requirement or research need?*

*What would you put on your wish list (whether practical or not) and which would be top priority?*

**Figures for wave height and/or storminess, by region, particularly for the 50-year return period.**

More accurate and relevant advance warning of extreme rainfall (most of the last several 'events' have either been predicted and not occurred, or occurred but not predicted). [This is outside the scope of the present study but is an interesting observation.]

**UKCIP02 CLIMATE CHANGE SCENARIOS: IMPLEMENTATION FOR FLOOD AND COASTAL DEFENCE: Record of telephone interview on the use of future climate change information in flood and coastal defence studies**

**Area of special interest: River and coastal engineering practice**

*Which aspects of your work require consideration of future climate change?*

Coastal flood management plans and strategy studies for the Environment Agency: involves looking at scenarios of climate and land-use change (ref CEH/HRW Modelling Decision Support Framework).

Procurement and defence schemes.

*How do you deal with them at present?*

Climate change calculations tend to be done as sensitivity tests. Predicted future changes are not usually included in cost-benefit analyses, or scheme selection decisions, although sustainability and ability to be changed as climate change becomes a reality are issues in design.

*Would you prefer to deal with them differently? Do you use UKCIP98 data? What information formats do/would you prefer?*

No to UKCIP98.

Why not include for sea level rise in design now, for example making walls 0.25m higher. It seems inefficient and to involve greater cost over the design life to revisit designs and upgrade walls, which could have been designed and built to allow for sea level rise originally (eg Humber). Possibly because of inconsistencies that might arise between different schemes considered by different practitioners or assessors. Possibly because there is enough conservatism elsewhere in designs, and because climate is only one of several aspects of variability, risk and uncertainty. [Comment relevant throughout the risk and uncertainty theme.]

Prefer prescriptive, as maps or tables, even if only plausible estimates rather than actual predictions.

*Do you know of any specific faults, difficulties, uncertainties, lack of data, situations not well dealt with at present?*

*Do you have any additional information requirement or research need?*

The present Hadley Centre ensemble averaging approach should improve reliability, but perhaps someone could come up with overall 'most reliable' predictions based on all scenarios and all global climate models. [Outside the scope of this study, but seems a good research topic.]

*What would you put on your wish list (whether practical or not) and which would be top priority?*

**Would like to see something directly applicable and reliable** (hopefully what UKCIP02 and associated studies will do).

## **UKCIP02 CLIMATE CHANGE SCENARIOS: IMPLEMENTATION FOR FLOOD AND COASTAL DEFENCE: Record of telephone interview on the use of future climate change information in flood and coastal defence studies**

### **Area of special interest: Fluvial flood risk**

*Which aspects of your work require consideration of future climate change?*

Virtually all flood estimates for EA work. Section 105 studies, flood strategy and so on. In general we stick to the current guidance of using 1 in 100 year flows plus 20% volume. The original paper that was used to derive this estimate was based on a small set of rivers (Thames, Severn etc.) but we find it a useful exercise for flood studies.

As a rule, we also look at the uncertainty related to data quality and flood estimation as a separate issue to climate change.

*How do you deal with them at present?*

- +20% volume on FEH derived flows with the exception of very small catchments where FEH is not used.
- Occasionally continuous simulation is used.
- Standard Defra guidance is followed.

*Would you prefer to deal with them differently? Do you use UKCIP98 data? What information formats do/would you prefer?*

- Prefer to have some specific guidance but are aware that the problems of downscaling make this quite difficult.
- It would be useful to have different increases in flow volume for different types of catchment (size, geology and so on).
- The main output should be the likely changes in extreme rainfall or flow at an appropriate fine scale.
- Specific guidance could be built into the FEH process without having to change the software in any way.

*Do you have any additional information requirement or research need?*

The updating of the FSR rainfall-runoff model is more urgent than anything else. Then, at least current flood estimates would be based on an analysis of recent historic data.

It would be possible to alter FSR RR parameters to look the sensitivity of flood estimates to changing climate inputs (SAAR, SPR, CWI were discussed) BUT prefer to used gauged records and the FEH statistical approach. In this case it would be most useful to have estimates of changes in flow that could be used to alter the outputs of a FEH statistical flood estimate.

The type of research required to derive these estimates was discussed. Possibly need continuous simulation on a range of catchments to provide seasonal variations in the volume of flood peaks.

*What would you put on your wish list (whether practical or not) and which would be top priority?*

Clear practical guidance based on sound science.

*Other*

JBA/WSA are involved in a project to determine an extreme (1 in 1000) floodplain map without climate change. The proposed approach involves developing tools to automate the process of converting FEH inflows to floodplain maps so any allowance for climate change could be built in at a later stage once the guidance is published. Alternatively it may be possible to state that new return period of each flood outline after 25, 50, 100 years of climate change impact.



## **Appendix 2      Outline proposals for further research requirements**

River flow change for different hydrological regions and durations

Total sea level rise and effects on extreme high and low waters

Wave climate change: height, period, direction and extremes

Coastal defence vulnerability assessment

Changes in high-intensity rainfall events

Climate change impacts on coastal morphology

**Title: River flow change for different hydrological regions and durations**

**(Key Customer) Purpose:**

Those authorities with responsibilities for flood protection and (maritime) flood defence will need to decide how predicted river flows, and hence the frequency of extreme water levels, will change as the climate changes. As river flow is perhaps the single most important issue for river engineers, and as the future rainfall predictions are made with some degree of confidence, it seems worth developing the rainfall results to provide more directly useful changes in flow rate and volume.

**Summary (Overall) Objectives**

To convert and expand upon information provided in the outputs from the UKCIP02 report to produce figures that directly address the issue of high and extreme river flow around the UK. Results will be derived from modelling of a number of different hydrological criteria, including catchment size and rainfall duration. This would probably involve CEH in running continuous simulations using existing river models for future rainfall, groundwater and catchment wetness conditions from a number of climate model scenarios.

**Context (Background)**

As rainfall may change as a consequence of global warming, so the probability of fluvial flooding may change. There are predictions of rainfall change in UKCIP02, and it could be assumed that percentage changes in river flow would be the same. However, this topic is of sufficient importance to justify further work on the relationship between rainfall and river flow, taking account of catchment type, rainfall duration and antecedent conditions.

**Main outputs/ User/ Benefits**

The main outputs would be in terms of predictions for extreme river flows for different periods into the future, for different parts of the UK, and for different catchment types, giving more detail than current standard allowances. Benefits in terms of more efficient investment in flood defences would come through more accurate predictions of changing flood risk and hence more accurate cost/benefit assessments.

**Timescale/ Costs/ Costs by year**

This research project could be negotiated immediately.

It is anticipated that this project would take approximately 18 months, and cost £75,000.

## **Title: Total sea level rise and effects on extreme high and low waters**

### **(Key Customer) Purpose:**

Those authorities with responsibilities for coastal protection and (maritime) flood defence will need to decide how predicted extreme water levels will change as the climate changes. As water level is perhaps the single most important issue for coastal engineers, and as the future predictions are made with some degree of confidence, it seems worth refining the results to provide more directly useful numbers.

### **Summary (Overall) Objectives**

To convert and expand upon information provided in the outputs from the UKCIP02 report to produce figures that directly address the issue of extreme high and low water levels around the UK. Results will be based on a combination of sea level rise, tidal range change and surge change to address extreme high and low water levels. This would probably involve POL in running continuous simulations using existing continental shelf models for future mean sea level and atmospheric conditions from a number of model scenarios. It was noted in UKCIP02 that surge predictions depend on which source climate model is used, so to improve upon existing predictions it will be necessary to try a number of climate models.

### **Context (Background)**

As sea levels increase and weather changes, as a consequence of global warming, so the probability of marine flooding and risk of damage will increase. While there are predictions in the UKCIP02 reports, confidence in the important extreme water level parameters would be increased by basing predictions on a range of climate model outputs. Extreme low waters are less important, but may be useful in terms of exposure of outfalls, intakes, structure toes etc, and could be estimated at the same time as the extreme high water levels.

### **Main outputs/ User/ Benefits**

The main outputs would be in terms of predictions for extreme water levels for different periods into the future and for different parts of the UK, giving more detail than current standard allowances, but made with more confidence than in UKCIP02. Benefits in terms of more efficient investment in coastal defence would come through more accurate predictions of changing flood risk and hence more accurate cost/benefit assessments.

### **Timescale/ Costs/ Costs by year**

This research project could be negotiated immediately.

It is anticipated that this project would take approximately 18 months, and cost £75,000.

## **Title: Wave climate change: height, period, direction and extremes**

### **(Key Customer) Purpose**

Those authorities with responsibilities for coastal protection and (maritime) flood defence need to take a view as to how wave climate may change as the climate changes. Wave climate is an essential input to most coastal studies, and as UKCIP02 does not venture a prediction due to lack of confidence in future wind predictions, any serious prediction of future conditions would be useful.

### **Summary (Overall) Objectives**

To provide information on change in wave height, wave period, wave direction and extremes, due to future climate change, in a form that can be incorporated into coastal engineering assessments. This could be done using the UKMO 12km model, with additional local modelling where additional resolution is needed.

### **Context (Background)**

Most coastal studies involve the use of wave climate information and most involve making some allowance for possible future climate change. At present, confidence in prediction of future wind conditions is low, and so the effort involved in a major wave climate modelling exercise may not be justified until wind predictions improve. At the stage of development when it is possible to make serious attempts at predicting changes in wave height, wave period, wave direction and extremes, it would be worth trying to improve on the present rather ad hoc approaches to potential wave climate change.

The importance of wave height and extremes is obvious, but wave period can also be important for run-up, overtopping and risk of flooding. Wave direction is relevant in wave transformation from offshore to inshore, and exposure of locations protected by headlands, and is critical in estimation of littoral drift rates.

### **Main Outputs/ User / Benefits**

The main outputs would be in terms of predictions of changing wave parameters and extremes for different periods into the future and for different parts of the UK. If possible, map regional changes (or at least realistic allowances) in wave height and direction. More detailed results would be presented as statistical summaries, in the form of wave roses, percentage exceedance tables and estimates of large wave heights (by season and/or direction). Benefits in terms of more efficient investment in coastal defence would come through more accurate predictions of changing flood risk and hence more accurate cost/benefit assessments.

### **Timescale/ Costs/ Costs by year**

This research project should be delayed until future wind predictions become more consistent.

It is anticipated that this project would take approximately 18 months, and cost £75,000 (over two financial years).

## **Title: Coastal defence vulnerability assessment**

### **(Key Customer) Purpose:**

Those authorities with responsibilities for coastal protection and (maritime) flood defence will need to decide on how existing and potential new, structures will perform as the climate changes.

### **Summary (Overall) Objectives**

To convert information provided in the outputs from the UKCIP02 report into a format that will allow the assessment of the vulnerability of existing coastal defences to changes in the climate, both in terms of their performance and structural stability. This research should be completed and disseminated within a year, and form the basis for strategic assessments of coastal defences around England and Wales thereafter.

### **Context (Background)**

As sea levels increase and weather changes, as a consequence of global warming, so the conditions that coastal defences have to resist will alter. While increases in mean sea level can be directly obtained from the UKCIP02 reports, many other parameters of interest to coastal managers and engineers will need to be derived subsequently. These include wave heights, wave directions and tidal surges. While the derivation of these “hydrodynamic” parameters is envisaged as being studied in other R&D projects, there remains the important issue of how to use the information to assess the vulnerability of existing defences, and to design improved or new defences if these are shown to be needed.

Deriving a uniform methodology to this type of assessment is recommended, as part of the continuing strategic approach to coastal defence management in England and Wales (and increasingly in Scotland as well).

### **Main outputs/ User/ Benefits**

The proposed research will set out a recommended approach to assessing the “vulnerability” of coastal defences, based on the best available predictions of how tidal levels, waves and other parameters are likely to change over the coming decades. Such an approach will necessarily have to be tailored to individual locations, to reflect both predicted regional changes (for example in mean sea level) and site-specific factors (e.g. exposure to a narrow wave direction sector, changes in foreshore levels).

This methodology will then be available to coastal local authorities and Environment Agency offices, or their consultants, to help decide upon the priorities for interventions such as strengthening or raising structures, or replacing them.

This standard methodology will also allow improved decision making, at a national level, both in regard to possible grant aid for specific coastal defence schemes and the long-term implications for defending the coastline of England and Wales to present-day standards.

**Timescale/ Costs/ Costs by year**

This research project should be started at the same time as, or very shortly after, other projects that convert results from UKCIP02 into information on future wave conditions and tidal levels.

It is anticipated that this project would take approximately 6 months, and cost £25,000 (in one financial year).

## **Title: Changes in high-intensity rainfall events**

### **(Key Customer) Purpose**

Climate change may have an effect on high-intensity rainfall events (durations of 15 to 60 minutes), with a consequent impact on urban drainage. A relatively small increase in rainfall volume over a short duration could cause a significant increase in the number of occasions in which drainage systems are overloaded. This is of potential interest to all local authorities and others with responsibilities for drainage of paved areas.

### **Summary (Overall) Objectives**

The first (feasibility) stage of this research will review the possibility of developing separate allowances for change in high-intensity rainfall, or whether allowances for possible change in longer duration rainfall are more appropriate. This will probably involve examination of existing (but unpublished) climate model results to see if valid allowances can be made for much shorter timescales than used in published rainfall scenarios. Depending on the outcome, a second (implementation) stage would develop the new allowances.

### **Context (Background)**

High-intensity rain falling on paved areas quickly enters drainage systems. When the drainage system becomes full, and can take no more water, a short period of localised flooding may occur. Where a drainage system frequently operates close to its maximum capacity, a small change in rainfall intensity could significantly increase that frequency of flooding.

### **Main Outputs/ User / Benefits**

Refined allowances for high-intensity rainfall would allow urban authorities to make more accurate assessments of any changes in drainage requirement following climate change. At present they have only allowances intended for use with rainfall durations of the order of several hours.

### **Timescale/ Costs/ Costs by year**

The feasibility stage of this research project could be started immediately, but if it proceeds to the implementation stage, this might benefit from the results of ongoing research on rainfall and river flow.

It is anticipated that the two stages of this project would take approximately 3 and 6 months, respectively, the two stages costing around £10,000 and £25,000.

## **Title: Climate change impacts on coastal morphology**

### **(Key Customer) Purpose**

Climate change, with increased sea levels, will alter the changes in both sediment transport and coastal morphology around England and Wales. Typical examples are the retreat of cliff tops and of barrier beaches such as Chesil. Given that our coastlines are generally impoverished in terms of sand and gravel, an increased rate of change is likely to result from increasing sea levels. This in turn will increase the pressures for expenditure on existing and perhaps new coastal defences in populated areas, or result in more rapid loss of land along unprotected rural coastlines.

### **Summary (Overall) Objectives**

This research will provide a generalised methodology for predicting the changes in coastal morphology in response to climate change, particularly of the expected recession rates of undefended cliffs and beaches.

### **Context (Background)**

The justification for coastal management, in particular the refurbishment or installation of coastal defences, often depends on estimates of future erosion rates that are expected to increase in response to global warming. Most of the methods used are empirical in nature, but if applied literally indicate a rapid increase in recession rates of soft cliffs and barrier beaches around the coastline of England and Wales.

Research is needed in order to decide which, if any, of the existing predictive methods can be regarded as reliable, based partly on retrospective analysis of past changes. This research would usefully build upon the present “FutureCoast” project being undertaken by Halcrow.

### **Main Outputs/ User / Benefits**

The proposed research will set out a recommended approach to assessing the future trends in coastal morphology based on the best available predictions of how tidal levels, waves and other parameters are likely to change over the coming decades, and verified against past changes in the coastline. Such an approach will necessarily have to be tailored to individual locations, to reflect both predicted regional changes (for example in mean sea level) and site-specific factors (e.g. character of underlying rock, availability of beach sediments).

This methodology will then be available to coastal local authorities and Environment Agency offices, or their consultants, to help decide upon the priorities for interventions such as strengthening or raising structures, or replacing them.

This standard methodology will also allow improved decision making, at a national level, both in regard to possible grant aid for specific coastal defence schemes and the long-term implications for defending the coastline of England and Wales to present-day standards.

**Timescale/ Costs/ Costs by year**

This research project should be started at the same time as, or very shortly after, other projects that convert results from UKCIP02 into information on future wave conditions and tidal levels.

It is anticipated that this project would take approximately 18 months, and cost £75,000 (over two financial years).