

Future flooding and coastal erosion risks

Edited by
Colin R. Thorne, Edward P. Evans
and Edmund C. Penning-Rowsell


thomas telford

Published by Thomas Telford Publishing, Thomas Telford Ltd, 1 Heron Quay, London E14 4JD.
www.thomastelford.com

Distributors for Thomas Telford books are

USA: ASCE Press, 1801 Alexander Bell Drive, Reston, VA 20191-4400

Japan: Maruzen Co. Ltd, Book Department, 3-10 Nihonbashi 2-chome, Chuo-ku, Tokyo 103

Australia: DA Books and Journals, 648 Whitehorse Road, Mitcham 3132, Victoria

First published 2007

Also available from Thomas Telford Books

Flood Risk Management. Edited by G. Fleming. ISBN 0 7277 3112 3

Coastal Defence – ICE Design and Practice Guide. Institution of Civil Engineers. ISBN 0 7277 3005 3

A catalogue record for this book is available from the British Library

ISBN: 978-0-7277-3449-5

© Queen's Printer and Controller of HMSO 2007

Copyright in the typographical arrangement and design vests in the Crown

Published under licence for the Department of Trade and Industry

Applications for reproduction should be made in writing to:

The Licensing Division, Her Majesty's Stationery Office, St Clements House, 2-16 Colegate, Norwich
NR3 1BQ

The contents of this publication is for information purposes only. The Crown accepts no liability for loss or damage of any kind howsoever arising as a result of actions taken in reliance on information contained in this publication.

All rights, including translation, reserved. Except as permitted by the Copyright, Designs and Patents Act 1988, no part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying or otherwise, without the prior written permission of the Publishing Director, Thomas Telford Publishing, Thomas Telford Ltd, 1 Heron Quay, London E14 4JD.

This book is published on the understanding that the authors are solely responsible for the statements made and opinions expressed in it and that its publication does not necessarily imply that such statements and/or opinions are or reflect the views or opinions of the publishers. While every effort has been made to ensure that the statements made and the opinions expressed in this publication provide a safe and accurate guide, no liability or responsibility can be accepted in this respect by the authors or publishers.

Typeset by Academic + Technical, Bristol

Printed and bound in Great Britain by MPG Books, Bodmin, Cornwall

Contents

Dedication	x
Preface – <i>Professor Sir David King</i>	xi
List of contributors	xiii
Part 1 Introduction	
1 Overview	3
<i>Edward P. Evans, Jim W. Hall, Edmund C. Penning-Rowsell and Colin R. Thorne</i>	
The task we have undertaken	3
The evolving policy context	4
The science and technology backdrop	5
Flood impacts and policy change	6
New directions in risk analysis	8
Scenario analysis	9
Post-project perspective	10
References	11
2 Introduction to the Foresight ‘Future Flooding’ methodology	13
<i>Jim W. Hall, Jonathan D. Simm and Edward P. Evans</i>	
Overview	13
Conceptual framework	15
Scenario analysis	18
Quantified flood risk assessment	22
Quantified analysis of responses	24
Expert analysis of drivers	24
Expert analysis of responses to flood risk	25
Discussion	26
References	27
3 Environmental impacts of future flood risk	29
<i>Andrew R. Watkinson, Robert J. Nicholls, David A. Sear and Laure Ledoux</i>	
Introduction	29
Environmental impacts of flood management	30
Environmental impacts of changes in flooding	33

Implications of current trends of change in flood management for the environment	36
Foresight futures and the environment	37
Environmental economics	41
Conclusions	44
Acknowledgements	44
References	44
Part 2 Drivers of flood risk	
4 Climate change	49
<i>Nick S. Reynard</i>	
Introduction	49
Precipitation	49
Temperature	50
Evapotranspiration	50
Changes in precipitation, temperature and evapotranspiration	50
Estimating the effects of climate change on flooding	56
Uncertainty	59
Conclusions	61
References	62
5 Catchment land-use	64
<i>Joe Morris and Howard Wheater</i>	
Introduction	64
Rural land-use management	65
Urbanisation	68
Agricultural impacts	70
Driver interactions	75
Driver behaviour under possible future scenarios	77
Conclusions	79
References	80
6 River processes	82
<i>Stuart N. Lane and C.R. Thorne</i>	
Introduction	82
Morphology and sediment supply	83
Conveyance	89
Environment, ecosystems and habitats	93
Case example: sediment delivery, morphological response and flood risk	96
Conclusions	97
References	98
7 Human behaviour	100
<i>David J. Ball and Colin H. Green</i>	
Introduction	100
The human behaviour drivers	102
Stakeholder behaviour	104
Public attitudes and expectations	106
Forecasting the effect of the human behaviour drivers on flood risk	112
Concluding remarks	114
References	114

8	Socio-economic drivers, cities and science	116
	<i>Colin H. Green and Edmund C. Penning-Rowsell</i>	
	Introduction	116
	Social impacts	116
	Economic and sectoral impacts	119
	Urban impacts	123
	Infrastructure impacts	126
	Science and technology	128
	Conclusions	130
	References	130
9	Coastal processes	132
	<i>Claire Hinton, Ian H. Townend and Robert J. Nicholls</i>	
	Introduction	132
	Coastal process driver set	132
	Future risk of coastal flooding	146
	References	147
10	Urban change	149
	<i>Adrian J. Saul and Richard M. Ashley</i>	
	Background	149
	The extent of the urban flooding	150
	Flood mechanisms in the intra-urban zone	151
	Primary flood mechanisms	151
	Secondary factors that increase or reduce flooding risk	154
	Summary of factors that influence urban flood risk	156
	Identification of relevant drivers	156
	Driver ranking and uncertainty	156
	Quantified flood risk – intra-urban	161
	Future research needs	168
	Summary	168
	References	169
11	Other flood risks and their drivers	173
	<i>Stuart N. Lane</i>	
	Groundwater flooding in permeable catchments	173
	Muddy floods	180
	Floods related to infrastructure and ordinary water courses outside indicative floodplains	182
	References	183
12	Driver impact scoring, ranking and uncertainty	185
	<i>Jonathan D. Simm, Colin R. Thorne and Jim W. Hall</i>	
	Introduction	185
	Driver impacts on local flood risk	186
	National driver impact scores	192
	Ranking driver impacts on future flood risk	193
	Uncertainty assessment	197
	Reconciliation of driver scores with the results of quantitative assessment of flood risk drivers	202
	Concluding remarks	204
	References	205

Part 3 Assessment of drivers and risks	
13 Quantitative assessment of driver impacts on future flood risk in England and Wales	209
<i>Jim W. Hall, Paul B. Sayers, Mike Panzeri and Robert Deakin</i>	
Introduction	209
Overview of the methodology	210
Methods for scenario-based future flood risk assessment	212
Results for the present situation	214
Results for future scenarios	216
The influence of global emissions on future flood risk	223
Conclusions	225
References	225
14 Driver impacts in Scotland	227
<i>Alan Werritty</i>	
Introduction	227
Climate change	228
Catchment land-use	230
River processes	232
Coastal processes	233
Human behaviour	236
Socio-economics	238
Ranking of drivers	239
References	242
15 Driver impacts in Northern Ireland	244
<i>John Chatterton and Stuart Suter</i>	
Background to flood risk in Northern Ireland	244
Climate change	252
River processes	255
Coastal processes and climate change	258
Socio-economic drivers	260
Closure	262
References	263
Part 4 Coastal erosion drivers and risks	
16 Drivers of coastal erosion	267
<i>Kevin Burgess, Helen Jay and Robert J. Nicholls</i>	
Introduction	267
Drivers – natural morphology and processes	268
Drivers – human intervention	270
Drivers – climate change	273
Case studies	274
References	279
17 Assessment of future coastal erosion risk	280
<i>Kevin Burgess, Helen Jay, Robert J. Nicholls, Colin Green and Edmund C. Penning-Rowsell</i>	
Introduction	280
Rates of change	280

Coastal defence	287
The economic impacts of coastal erosion	289
References	292
Part 5 Responses to future flood and coastal erosion risks	
18 Managing the rural landscape	297
<i>Stuart N. Lane, Joe Morris, P. Edna O'Connell and Paul F. Quinn</i>	
Introduction	297
Management of infiltration	298
Catchment-wide storage	305
Management of hillslope and river conveyance	311
Conclusions	315
References	317
19 Responses to future intra-urban flood risks	320
<i>Richard M. Ashley and Adrian J. Saul</i>	
Introduction	320
The potential responses	320
Response groups and effectiveness	321
Quantification of responses	329
Sustainability assessment	334
References	338
20 Flood event management	340
<i>Sue Tapsell and David Ball</i>	
Introduction	340
Data collection	341
Response measures for managing flood events	342
Real-time flood forecasting and warning dissemination	343
Flood fighting: actions to manage flood waters and defences during the event	345
Collective-scale damage-avoidance actions: evacuation of floodplains and coastal areas at risk	347
Individual-scale damage-avoidance actions: temporary flood proofing and moving of assets at risk to safety	348
Potential application of measures to future scenarios	349
Sustainability issues	353
Future uncertainty	357
Conclusions	357
References	358
21 Reducing flood losses	360
<i>Nigel W. Arnell and John Chatterton</i>	
Introduction: A classification of approaches	360
Facilitating recovery from loss: insurance and public relief	360
Spatial planning for reducing flood losses	363
Flood-proofing and building standards	367
Implications for future national flood losses	369
Sustainability appraisal of measures to reduce flood losses	372
Conclusions	373
References	373

22 River engineering responses	375
<i>Peter H. von Lany and John Palmer</i>	
Introduction	375
Response group descriptions	376
Governance, costs and standards of service	381
Flood risk multipliers under the Foresight scenarios	385
Sustainability	386
Summary	389
References	390
23 The management of coastal flooding and erosion	392
<i>Robert J. Nicholls, Nicholas J. Cooper and Ian H. Townend</i>	
Introduction	392
Coastal defences	392
Coastal energy reduction measures	396
Re-alignment of defence infrastructure	399
Morphological protection	402
Use of the coastal response groups	404
Conclusions and emerging issues	410
Acknowledgements	411
References	411
24 Response scoring, ranking, uncertainty and sustainability	414
<i>Jonathan D. Simm and Colin R. Thorne</i>	
Introduction	414
Expert scoring of potential flood risk reductions	416
Process support using electronic spreadsheets	417
Response group scoring	418
Combining interdependent response groups	419
Ranking responses to future flood risk	421
Commentary	421
Uncertainty assessment	423
Sustainability analysis	426
Reference	429
Part 6 Assessment of flood risk responses	
25 Quantitative assessment of future flood risk management portfolios in England and Wales	433
<i>Paul B. Sayers, Jim W. Hall, Mike Panzeri and Robert Deakin</i>	
Introduction	433
Overview of the methodology	433
Future fluvial and coastal flood risk	444
Results of the investment analysis	451
Conclusions	457
References	457
Part 7 Sustainability and governance	
26 Sustainability of flood risk management responses	461
<i>Andrew R. Watkinson, Sarah E. Cornell and Robert Tinch</i>	
A long-term view of sustainability	461

Sustainability implications of responses to flood risk	462
Cost-effectiveness	465
Environmental quality	468
Social justice	471
Decisions today for future sustainability	472
References	473
27 The Governance of responses	475
<i>Andrew R. Watkinson, Sarah E. Cornell and Andrew Jordan</i>	
Introduction	475
Governance in the future	477
Governance options for a portfolio approach	484
Obstacles and opportunities	484
References	487
Part 8 Synthesis	
28 Strategic choices	491
<i>Andrew R. Watkinson, Edward P. Evans, Jim W. Hall, Edmund C. Penning-Rowsell and Colin R. Thorne</i>	
Introduction	491
Options for managing flood risk	491
A route map for flood management	495
Building a portfolio of responses	500
Conclusion	503
References	504
Index	505

Dedicated to

Elieen, Pia and Jacky

Preface

I am delighted to provide a preface to this publication on the research that lay behind the important and highly influential Foresight Future Flooding Report, published in two volumes in 2004.

Flooding is an issue that affects us all. Over £200 billion worth of assets are at risk around British rivers and coasts and those risks are likely to increase over the next 100 years due to changes in climate and society. In 2002 I therefore commissioned the Foresight Project on Flood and Coastal Defence to address a number of issues surrounding how the flood risk might change and how government and the private sector might best respond to the future challenges. The report that emerged had several key messages for government – flood risk would continue to rise to unacceptable levels; those risks had to be tackled on a broad front and hard choices would have to be made regarding where to direct investment. This work established a new paradigm for futures work and, with the issues of flooding and flood prevention continuing to be in the headlines worldwide, it rightly continues to command widespread interest.

This book is edited by three of the team who undertook the original Foresight study and elaborates on the work undertaken by approximately 60 leading experts in the field, over 20 months between 2002 to 2004. A great deal of work was necessary to produce the evidence base that underpins the Future Flooding Report. However, the published documents contain only brief summaries of the deep descriptions, quantitative analyses and risk models developed and applied in the study. It is therefore most welcome that Thomas Telford have published this monograph as a detailed record of the science and engineering research performed during the Foresight Project on Flood and Coastal Defence.

The UK government fully appreciates the threats posed by flooding and is already supporting cutting-edge techniques and policies for managing flood risk. It is investing heavily in research to develop new and innovative approaches to flood risk management, based on applying holistic principles and achieving sustainable outcomes. However, the government is not complacent and recognises that more needs to be done. At the conclusion of the Foresight Project in 2004, the Minister with responsibility for flood management acknowledged the important role that the results of that research would play in preparing a government-wide strategy for managing the risks of flooding and coastal erosion. In order to capitalise on the knowledge gained during the study, he therefore established a Flood Action Plan, which is on-going. It involves all the relevant branches of government – a fine example of how scientific evidence can be used to inform better policy decisions.

Of course, the benefits of taking a long-term and far-sighted approach to flood risk management in a changing world are not unique to the UK. There has been a great deal of international interest in the Foresight model – the Foresight team have had

some very useful discussions with interested parties from the Netherlands, Japan, the USA and India, and there have also been Foresight Future Flooding missions to China and Russia.

Clearly, the work begun with the Foresight Flooding Project has not ended but will continue in the coming years and decades, both in the UK and overseas. The issues covered by the Foresight study are likely to assume increasing importance as we enter an era of climate change, economic growth and societal evolution. This volume will therefore be a valuable resource to scientists, engineers and a wide range of stakeholders who share a common concern for flood risk management and an interest in evidence-based policy making.

*Sir David King
Government Chief Scientific Adviser
June 2006*

List of contributors

Nigel W. Arnell	Tyndall Centre for Climate Change Research, School of Geography, University of Southampton, Southampton, Hampshire SO17 1BJ
Richard M. Ashley	Pennine Water Group, Department of Civil and Structural Engineering, University of Sheffield, Sheffield S1 3JD
David Ball	Centre for Decision Analysis and Risk Management, Middlesex University, Enfield, London EN3 4SA
Kevin Burgess	Halcrow, Burderop Park, Swindon, Wiltshire SN4 0QD
John Chatterton	John Chatterton Associates, 32 Windermere Road, Moseley, Birmingham B13 9JP
Nick J. Cooper	ABP Marine Environmental Research Ltd, Suite B, Waterside House, Southampton, Hampshire SO14 2AQ Now, Royal Haskoning, Marlborough Crescent, Newcastle upon Tyne NE1 4EE
Sarah E. Cornell	Tyndall Centre for Climate Change Research, Department of Earth Sciences, University of Bristol, Bristol BS8 1RJ
Rob Deakin	Halcrow, Burderop Park, Swindon, Wiltshire SN4 0QD
Edward P. Evans	'Bevis', Great Somerford, Chippenham, Wiltshire SN15 5JA
Colin H. Green	Flood Hazard Research Centre, Middlesex University, Enfield, London EN3 4SA
Jim W. Hall	School of Civil Engineering and Geosciences, University of Newcastle upon Tyne, Newcastle upon Tyne NE1 7RU
Claire Hinton	ABP Marine Environmental Research Ltd, Suite B, Waterside House, Southampton, Hampshire SO14 2AQ
Helen Jay	Halcrow, Burderop Park, Swindon, Wiltshire SN4 0QD
Andrew Jordan	School of Environmental Sciences, University of East Anglia, Norwich, Norfolk NR4 7TJ
Stuart N. Lane	Department of Geography, University of Durham, Durham DH1 3LE
Peter H. von Lany	Halcrow, Burderop Park, Swindon, Wiltshire SN4 0QD
Laure Ledoux	Environmental Futures, 54 Rue Jean Baptiste Esch L1473, Luxembourg

List of contributors

Joe Morris	Institute of Water and Environment, Cranfield University, Silsoe, Bedfordshire MK45 4DT
Robert J. Nicholls	Tyndall Centre for Climate Change Research, School of Civil Engineering and the Environment, University of Southampton, Southampton, Hampshire SO17 1BJ
P. Enda O'Connell	School of Civil Engineering and Geosciences, University of Newcastle upon Tyne, Newcastle upon Tyne NE1 7RU
John Palmer	Halcrow, Burderop Park, Swindon, Wiltshire SN4 0QD
Mike Panzeri	HR Wallingford, Howbery Park, Wallingford, Oxfordshire OX10 8BA
Edmund C. Penning-Rowse	Flood Hazard Research Centre, Middlesex University, Enfield, London EN3 4SA
Paul F. Quinn	School of Civil Engineering and Geosciences, University of Newcastle upon Tyne, Newcastle upon Tyne NE1 7RU
Nick S. Reynard	Centre for Ecology and Hydrology, Wallingford, Oxfordshire OX10 8BB
Adrian J. Saul	Pennine Water Group, Department of Civil and Structural Engineering, University of Sheffield, Sheffield S1 3JD
Paul B. Sayers	HR Wallingford, Howbery Park, Wallingford, Oxfordshire OX10 8BA
David A. Sear	School of Geography, University of Southampton, Southampton, Hampshire SO17 1BJ
Jonathan D. Simm	HR Wallingford, Howbery Park, Wallingford, Oxfordshire OX10 8BA
Stuart Suter	Halcrow, Burderop Park, Swindon, Wiltshire SN4 0QD
Sue Tapsell	Flood Hazard Research Centre, Middlesex University, Enfield, London EN3 4SA
Colin R. Thorne	School of Geography, University of Nottingham, University Park, Nottingham NG7 2RD
Robert Tinch	Tyndall Centre for Climate Change Research, Schools of Biological and Environmental Sciences, University of East Anglia, Norwich, Norfolk NR4 7TJ
Ian H. Townend	ABP Marine Environmental Research Ltd, Suite B, Waterside House, Southampton, Hampshire SO14 2AQ Now, Hydraulics Research Wallingford Ltd, Howbery Park, Wallingford, Oxfordshire OX10 8BA
Andrew R. Watkinson	Tyndall Centre for Climate Change Research, Schools of Biological and Environmental Sciences, University of East Anglia, Norwich, Norfolk NR4 7TJ
Alan Werritty	Department of Geography, University of Dundee, Dundee DD1 4HN
Howard Wheeler	Imperial College London, South Kensington, London SW7 2AZ

7 Human behaviour

David J. Ball and Colin H. Green

Introduction

From a social science perspective our primary interest is in the nature of, and relationships between, individuals and groups, where those relationships notably include power and the roles of each group. It is through these relationships in particular by which we attempt to understand the world.

Thus, from a social science perspective, the Foresight 'Future Flooding' exercise is itself worthy of study as a social experience, and as an expression of the clash of what Braudel (1995) would describe as 'civilisations'; the Foresight process sought to reconcile the two quite different understandings of the world represented by the physical sciences and the social sciences. As a social process, it expressed quite different understandings of such concepts as risk, uncertainty, vulnerability and the future.

Of these two conflicting worldviews, that of the physical sciences dominated and while the determinism was reassuring we nonetheless experienced a degree of discomfort in seeking to fit our understandings into a strong physical science framework. But the challenge laid down by the physical scientists, namely, how can we predict the future and how, consequently, can we choose the future, is one which social scientists should welcome, not least because it is revealing of one's own preconceptions and assumptions.

The approach taken by the Foresight programme on flood risk management and coastal defence was anchored in an essentially deterministic worldview. This is readily apparent from the way in which the process of risk change is seen to result directly from an array of factors, physical, climatological, and even social, termed 'drivers,' whose effects on the socio-environmental system can be modelled to predict consequences.

The power of this type of approach is that change can be simulated, by computer if necessary, predictions made on the state of the future, and if the predictions are not liked, then the effect of hypothetical interventions of various kinds can be simulated by adjusting the model accordingly. Such systems, if they work, are invaluable to decision makers. Of course, it is now recognised that even those processes which are outwardly deterministic are not entirely certain or predictable, as chaos theory and even experience demonstrate. For example, the Pioneer 10 spacecraft which was launched in the 1970s and is now far beyond the orbit of Pluto, has steadily deviated by some 400 000 km from its predicted course. No one has so far been able to explain

this curious behaviour (Anon., 2005). Hence, even in the presence of a seemingly deterministic system, uncertainties are present and estimating these constitutes an important element of any study including the Foresight one.

However, while the above classical worldview, which some call the Rational Action Worldview (or Paradigm, hence *RAP*) (Jaeger *et al.*, 2001), is more or less a taken-for-granted of Western thought and provides the foundation for a wide variety of institutions – markets, governments, international security, industrial management, healthcare – it is not the only conceivable theoretical approach. Indeed, behavioural and social science usually has more modest, or at least different, ambitions, recognising that human behaviour is a rather complex business and subject to influence by a vast array of factors, only some of which are amenable to deterministic-style forecasting (Eiser, 2004).

Thus, the world is taken to exist ‘out there’ whereas the social science approach both tends to see the world as being constructed and as being constructed through human interaction. From this viewpoint, floods are not simply extreme physical events inflicting themselves upon innocent and unsuspecting people, but highly interactive processes that involve inputs from both nature and society. As such, the very definition of a ‘flood’ becomes problematic. Within this framing, such complex systems are arguably more readily analysed by recourse to alternative sociological models, some of which are located in Fig. 7.1, but these could not be expected to produce the kinds of outputs demanded by the Foresight methodology. This figure can be contrasted to the models presented elsewhere in this volume.

For this reason, while bearing in mind the inevitable shortcomings of any model, an attempt was made to fashion an approach which would lend itself to Foresight as originally envisaged by its designers. In particular, in each of the four scenarios adopted in the Foresight study, the social scientist is inclined to the view that each then determines how floods will be understood, how decisions will be made, and how the flood risk will be managed. Thus, concepts such as ‘vulnerability’ and

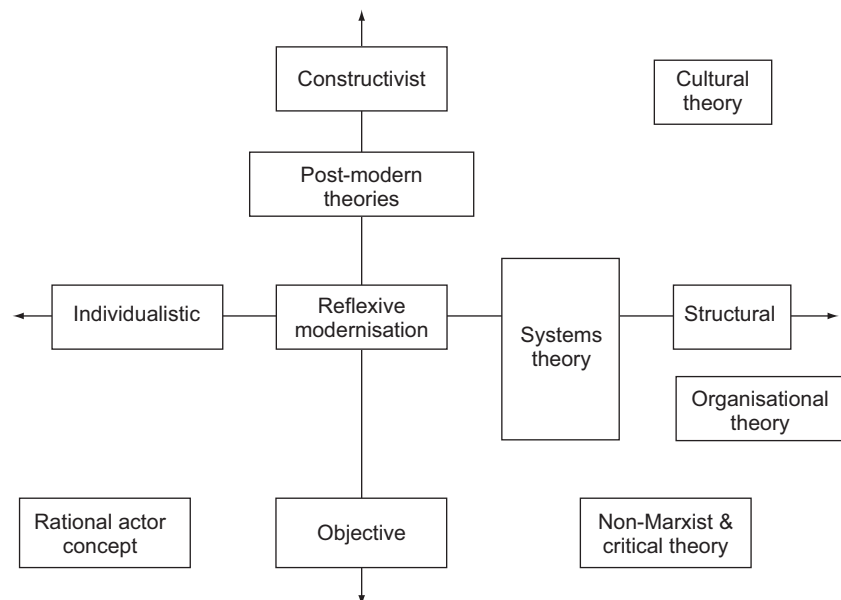


Fig. 7.1. Renn (1994) has classified the major sociological perspectives on risk according to their anchorage in a) an individualistic versus structural dimension and b) an objectivist versus constructivist dimension. The Rational Actor Paradigm of the Foresight programme inhabits the bottom left (individualistic-objective) quadrant of this classification

'risk' will be defined uniquely by each society in different ways. Rather than it being possible to define such terms as vulnerability, risk and uncertainty in ontological terms, they must then be understood epistemologically.

So, for example, a probability is a claim as to what we can know and how or why we can know it, and a claim which can properly be expressed in terms consistent with Kolmogorov's mathematics of probability. In that there are competing theories of probability, there are different claims as to what we can know and the basis upon which we can know it. In short, if we could determine which form of society would exist, then there would be no choices left to make except in that each society would be faced with resolving its own internal contradictions. Similarly, the distinction between society and technology should be regarded a false dichotomy.

The human behaviour drivers

With the above important caveat in mind, human behaviour was deemed for the purposes of this study to comprise two drivers, denoted as 'stakeholder behaviour' and 'public preferences' (attitudes and expectations). These were defined as follows.

Stakeholder behaviour

Stakeholders include any group, cohesive or dispersed, with a direct or indirect interest or influence on flood risk and its management. The public is clearly an important stakeholder but is not seen as having a single opinion. Stakeholder behaviour, expert or lay, is seen as motivated by numerous factors besides risk. These include beliefs, values, ways of working, and perceived fairness of decision processes.

Public attitudes and expectations

In line with cultural theory (Douglas, 1985; Schwarz and Thompson, 1990) the public is not regarded as a single entity with one position on matters related to flood risk. Attitudes and expectations are seen to be determined by multiple factors including actual and perceived risk, equity concerns, issues of process (i.e. the means and manner by which risk management decisions are made) and world view.

It is self-evident that these drivers are closely inter-related. The 'public' has been singled out as one stakeholder group in terms of its preferences, and is clearly one contributor to 'stakeholder behaviour' overall, which will be driven partly by public preferences. Social impacts (see Chapter 8) will clearly influence preferences, especially those of the public, and hence behaviour. Other stakeholder groups – farming, insurance, etc. – will have their own strong preferences too. Because the ways in which the livelihoods of these latter communities are linked with flood risk management are better defined, it may be expected, though is not guaranteed, that their preferences will be less diverse within their own group than those of the public at large.

This framing positions people and groups as though they were physical phenomena to be taken into account in decision making. But people differ from physical phenomena in two key aspects. First, people are the decision makers; it is out of the cognitions and relationships between individuals and groups that decisions will emerge. Second, if research is about learning, when the researcher seeks to learn about the physical world the physical world does not learn anything about the researcher. But when the researcher seeks to learn about the social world, the people studied are changed to a greater or lesser extent by the experience.

Hence, the main impact of these drivers upon flood risk is likely to be by way of their influence upon other actors, such as regulators. Thus there will be strong feedback loops, e.g. between stakeholder behaviour and regulation and other drivers. Regulators will be tuned in to stakeholder behaviour and public expectations in

deciding on risk management interventions. But stakeholder behaviour and public expectations will in turn be influenced by the ways in which regulators make choices, as well as actual choices made. In turn, the roles of individuals and groups, and the inter-relations between them, are both defined by and define the society and can be taken to reflect the worldview of that society.

The concept of 'regulators' is itself predicated upon the existence of a particular form of society, being most closely associated with the form of society defined as 'national enterprise'. In the world markets model, with its emphasis upon both the market and individualism, and a desire to minimise the scope of government, the emphasis would be on the use of prices and formal regulation would be minimised. Under the purist form of cultural theory (Adams, 1995), once the nature of the society is determined, there are no choices left to make.

Overall feedback is thus strong, complicated, and perhaps even unfathomable. Furthermore, the stakeholder groups that have the most influence upon regulatory decisions, and who are therefore most likely to feel enfranchised and therefore satisfied, will vary from one Foresight scenario to another, though not in a simple or predictable way. This is because it is as much the 'fine structure' of the scenarios which will be important as their broad brush nature. Self-interest, beliefs, (dis-)satisfaction and ways of working will provide the energy to drive the stakeholder behaviour-regulation cycle, and this energy will in turn be topped up by, among other things, that stakeholder group denoted as 'the public' in the driver listing. 'Public preferences' will in turn be fuelled as much if not more by perception of the regulatory process than the actual risk, and this in its turn will be fed by other drivers such as 'institutions', 'science, engineering and technology' and 'risk compensation and insurance' through their attitudes to the public and the public's then view of their rights to involvement and say in regulatory choice.

In view of the large number of stakeholders, there are inevitably other kinds of stakeholder behaviour which will impinge on other drivers. Agricultural practices, for example, could clearly have a big impact on runoff. Similarly, the insurance industry can be regarded as a separate player or the actions of the insurance industry can be understood in relation to the actions of other players (Green and Penning-Rowsell, 2004). Notably, flooding is seen as uninsurable risk except through some form of public-private partnership (Gaschen *et al.*, 1998).

Likewise, the behaviour of the insurance sector – an essentially free market – will have an effect on what is demanded of flood risk managers. Already there is speculation that the insurance sector, faced with rising flood-related claims, might opt for novel risk-transfer or hedging instruments such as catastrophe bonds which transfer the risks to global capital markets (Linnerooth-Bayer and Amendola, 2003).

Mitchell (2003) gives the following salutary example of the complexity of stakeholder behavioural impacts, this in the context of the selection of port locations for industries:

... the burgeoning emphasis on port locations for industries is facilitated by changes in a complex web of factors that includes, among other things, marine transportation, navigation, and dredging technologies; shipboard labor practices; vessel registration and regulation rules; the acquisition of new electronic skills by mariners; the profitability of the shipping industry; and the state of competition between different transportation modes. In turn these components are embedded in a dominant consumer-oriented economy that is made possible by fluid supplies of investment capital and preferences for entrepreneurial risk-taking, coupled with precisely segmented and targeted marketing strategies that rely on vast quantities of timely and comprehensive information about consumer tastes and surplus income.

Index

Page numbers in italics refer to diagrams and illustrations. The abbreviation WM/NE/LS/GS refers to the world markets, national enterprise, local stewardship and global sustainability scenarios of the Foresight Future Flooding Project.

- above-ground storage
 - intra-urban flood management 326, 327
 - WM/NE/LS/GS 337
 - sustainability 327
 - types 326, 327
- afforestation
 - catchment run-off 67
 - flood damage 71
 - flood risk adjustments 302
- agri-environmental schemes 299, 303–304
- agriculture
 - see also* afforestation; rural land management; rural land-use
 - buffer strips 301–302
 - coastal grazing marshes 32, 36, 40, 41
 - crop sensitivity 71–72
 - drivers 70–71, 197
 - farm management practices 299–300
 - field drainage 67, 301
 - flooding economics 73–75
 - impact
 - Northern Ireland 250–251
 - Scotland 232
 - land drainage 251, 300–301
 - livestock management 300
 - ploughing times 299
 - soil flooding impact 73–75
 - tillage regimes 300
 - water table depths 72–73
 - WM/NE/LS/GS damage projections 222, 223, 455
- annual average damage 188, 210
- aquifers 177, 178
- bank erosion, rivers and streams 301
- beaches
 - future instability 287
 - regeneration 397, 398
- shingle nourishment 397, 398
- stabilisation
 - breakwaters 271, 272
 - groynes 271, 271
- below-ground storage
 - intra-urban flood management 326–327
 - WM/NE/LS/GS 337
 - types 326–327
- breakwaters, as coastal defences 396, 396, 397
- Brunn Rule, coastal erosion 284
- buffer strips 301–302
- buildings
 - design, flood risk management 321–322
 - flood proofing 367–368
 - roof drainage 322
 - stormwater storage 322
 - sustainability, WM/NE/LS/GS 335
 - temporary flood measures 349
- catchments 64
 - drivers
 - rankings 194–197
 - Scottish 239–240
 - and future flood risks 77–79
 - storage 308–309
 - and conveyance management 313–314
 - governance 307
 - impoundments 306–307
 - ponds, bunds and ditches 306
 - sustainability 307–308
 - uncertainty 309–311
 - wetlands and washlands 306
 - WM/NE/LS/GS uncertainties 199–201
- charitable relief, flood losses 362
- cliff erosion 272
 - hard-rock 277, 277
 - as sediment provider 272

- climate change
 - and coastal defences 287–288
 - and coastal erosion 273–274, 284–287, 286
 - controlling, implications 494–495
 - and emissions 223, 224, 457
 - evapotranspiration rates 55–56, 56
 - and flooding frequency 56–57, 58, 59, 218, 219
 - as flooding source 496–497
 - precipitation 19, 51, 53–55, 164
 - scenarios 18–20, 18, 19
 - Scottish drivers 239–240
 - and sea levels 5, 19
 - temperatures 19
 - and urban flooding 155
 - vegetative growth 258
- coastal defences 392
 - see also* storm surges
 - beaches
 - regeneration 397, 398
 - stabilisation 271, 271, 272
 - breakwaters, offshore 396, 396, 397
 - by energy reduction 396–397
 - sustainability 408–409
 - by morphological protection 402–404
 - and climate change 287–288
 - costs 394
 - current expenditure 284
 - dune stabilisation 271–272
 - environmental implications 399, 468–469
 - failure, overtopping 393–394, 393, 394
 - future investments 288–289, 289
 - geomorphological engineering 402–403
 - glacial sediment beaches 275, 275
 - interactions 395
 - and land values 468
 - lifespan 289
 - maintenance 394–395
 - man-made 269
 - morphological protection 402–404, 469
 - sustainability 408–409
 - Northern Ireland 247–248
 - re-alignments
 - managed 399–402, 410, 469
 - sustainability 408–409
 - transport implications 400–401
 - reclaimed land 278, 278
 - reduction implications 399–400
 - renewable energy production 396, 398–399, 410–411
 - response groups
 - effectiveness 407–410
 - WM/NE/LS/GS 404–407
 - responsibilities for 394
 - saltmarsh regeneration 398
 - Scotland 394
 - shingle beaches 276, 276
 - sustainability 408–409
- coastal erosion
 - Brunn Rule 284
 - cliffs 272
 - and climate change 273–274, 284–287, 286
 - and coastal morphology 268–270
 - current shoreline changes 280–282, 281
 - economic impacts 289–292, 290
 - hard-rock cliffs 277, 277
 - hotspots 291–292
 - impact of 32
 - and land values 290
 - Northern Ireland 259–260
 - and sea levels 285–287
 - shoreline changes, shoreline 282–284
 - storm surges 268
 - wave action 268
 - WM/NE/LS/GS
 - drivers 270
 - rates 285–287, 286, 290–291, 290
- coastal flooding
 - concentrations of 215–216
 - driver rankings 193–196
 - evacuation 347–348
 - and morphology 146
 - Northern Ireland 247–248, 260–261
 - perceived risks from 384
 - risk reduction, social justice 471–472
 - sustainability responses 462–463, 465–466
 - urban inundation 153
 - WM/NE/LS/GS
 - projections 218, 223
 - uncertainties 199–201
- coastal grazing marshes 32, 36
 - loss of 40, 41, 469
- coastal morphology 143–144
 - and coastal erosion 268–270
 - future uncertainty 145, 146
 - and sea levels 144–145
 - sediment supply 144–145
 - WM/NE/LS/GS sensitivity 269–270
- coastal processes, Scottish drivers 240–241
- coastal squeeze, estuaries 33, 273
- coincident flooding, cost per property,
 - future 331
- communal solidarity
 - flood event management 353
 - and natural disasters 117
- Community Flood Log Books 343
- community funding, flood-proofing 349
- computational hydraulic modelling,
 - development 5
- conveyance *see* river conveyance
- domestic losses
 - assets 349
 - minimising 349
 - property, expected annual damage 329–330

- WM/NE/LS/GS 119–120, 121
 - sewerage causes 165–166
 - storms 165–166
- drainage
 - see also* field drainage; sewers
 - form, maintenance and operations, WM/NE/LS/GS 338
 - infiltration, groundwater table levels 325–326
- drivers 16
 - analysis of 24–25
 - catchment rankings 194–197
 - classifications 17, 25
 - coastal flooding rankings 193–196
 - impacts on local flood risks 186–191
 - public attitudes as 190
 - ranking compilation 189
 - reconciled future impact 202–204
 - science and technology 190–191
 - uncertainty sources 197–199
 - WM/NE/LS/GS
 - multipliers 191–193
 - rankings 193–197
- dune stabilisation 271–272
- economic impacts, coastal erosion 289–292, 290
- economic output, definitions 128–129
- ecosystems
 - see also* environments
 - as defined user groups 93–94
 - flood management impact 31
 - protected habitats 94–95
 - within fluvial systems 34–35
- emissions, and climate change 223, 224, 457
- environments
 - see also* ecosystems; environments by name
 - agri-environment schemes 299
 - coastal defences 399, 468–469
 - economics 41–44
 - flood risk impacts 30–33, 94
 - intra-urban flood management 470–471
 - regulatory changes 94, 95–96
 - uncertainties within 95–96
 - WM/NE/LS/GS scenarios 38–40, 41, 95–96
- estuaries
 - coastal grazing marshes 32, 36, 40, 41
 - coastal squeeze 33, 273
 - land reclamation 31–32
 - morphological modifications to 272–273, 273
- evacuation 347–348, 351
 - decision making 348
- evapotranspiration rates 50, 55–56, 56
- extreme event management 324–325
- farming *see* agriculture
- fatalities, and flood risks 118
- fauna, river entrainment 233
- field drainage 67, 301
- flood damage
 - current estimates 215–216
 - definitions 187–188
 - economics 187, 212
 - estimates 6, 188
 - social vulnerability 212
 - WM/NE/LS/GS
 - agricultural production 222, 223, 455
 - estimated annual 452–453, 455
 - projections 218, 221
- flood defences
 - see also* coastal defences; river defences
 - costs 383
 - failure probability 211
 - and flood risk assessments 211
 - Foresight Futures Project, cost estimates 441
 - future investment costs 456–457
 - intertidal area reduction 31–32
 - and land values 468
 - reclaimed land 278, 278
 - reliance on 4–5
 - and shoreline movement 282–284
 - Standard of Protection 211
 - technical basis for 5
 - traditional 315–316
- flood event management
 - data sources 341
 - evacuation 347–348, 351
 - flood fighting
 - temporary measures 348–349
 - water-level control structures 345–347
 - forecasting 343–344, 351
 - funding 345
 - governance 345
 - information dissemination 343–345
 - responses 344–345
 - global sustainability scenario 352
 - governance 345, 485
 - local stewardship 353
 - national enterprise scenario 351–352
 - pre-event 342
 - planning 342–343
 - public awareness raising 342–343
 - risk logbooks 343
 - risk maps 343
 - sustainability 354, 354
 - sustainability issues
 - flood defence schemes 354, 355
 - floodplain evacuation 356, 357
 - forecasting 354, 355
 - pre-event 354, 354
 - temporary flood proofing 356, 357
 - uncertainties 357
 - world markets scenario 350–351

- flood insurance 360–361, 481–482, 481
 - future 369–370, 482–483
 - international aspects 361
 - provision 361–362
 - public charitable relief 362
 - sector, as stakeholders 103
 - self- 362–363
 - state aid/compensation 362
- flood losses
 - see also* flood insurance; flood reduction
 - domestic 349
 - expected annual damage 329–330
 - minimising 349
 - WM/NE/LS/GS 119–120, 121, 165–166
 - governance 486
- flood mapping 5
- flood plans, family and community 343
- flood proofing, retro-fitting 367–368
- flood reduction
 - future measures, effectiveness 370–372
 - policies 363–364, 370
 - social justice 471–472
 - spatial planning 363–364
 - sustainability 372–373, 372
 - through planning controls 364–366
 - WM/NE/LS/GS 369, 371
- flood return periods, Northern Ireland 256–258, 257
- flood risk assessments 22–23, 23
 - data availability 211, 212–213
 - defences failures 211
 - and flood defences 211
 - and flood risk management 213–214
 - floodplain areas 214–215, 215
 - methodology 210, 211, 225
- flood risk management
 - costs, future 491–494
 - ecosystems, impact 31
 - environmental impacts 30–33, 38–41
 - evolution of 4, 6–7
 - expected annual damage, WM/NE/LS/GS 452–453, 455
 - and flood risk assessments 213–214
 - Foresight Futures Project, responses 437–440
 - and insurance 483
 - Northern Ireland 244, 248–250
 - policies 36–37, 93
 - reduction responses
 - defence engineering 418–419
 - interdependence 419–420
 - methodology 416–417
 - multipliers 417–419
 - sustainability analysis 426–429, 429
 - urban fabric 418–419
 - WM/NE/LS/GS rankings 421–423
 - WM/NE/LS/GS uncertainties 423–426
 - response mechanisms 496
 - adaptability 499–500
 - governance 501–503
 - portfolio 500–501
 - time factors 498–499
- rivers 381–382
 - costs 382–383
 - governance 382
 - proportionate responses 383–384
- Scotland 227–228, 233, 236–237
- sustainability 37, 237
- WM/NE/LS/GS 109
- flood risks
 - see also* coastal flooding
 - afforestation 302
 - as annual average damage 188, 210
 - changes to 17
 - definitions 16, 210
 - fatalities, potential 118
 - future projections 112–113, 123
 - intangible 118–119, 118
 - low income groups 117
 - mapping 343
 - morphology 82
 - multipliers 188–189
 - Northern Ireland 246–247, 248, 260, 261, 262–263
 - public attitudes 102–103
 - quantified analysis 24
 - responses to 25–26
 - rivers
 - future increases 384–385
 - WM/NE/LS/GS multipliers 385–386
 - social impacts 116–117
 - and temperatures 50
 - WM/NE/LS/GS 78–79, 191–193, 216
- flood storage, rivers 378–379
- flood victims
 - fatalities 118
 - social support 119
- flood waves, urban 152
- flood-water transfer, rivers 379–380
- flooding frequencies
 - changes 53–54, 54
 - and climate change 56–57, 58, 59, 218, 219
- flooding systems
 - changes in 15–17
 - definitions 15, 16
 - instantaneous states 16
 - risk estimates 17, 17
- floodplains
 - see also* washlands
 - agricultural management on 67–68
 - classifications 215, 215
 - evacuation 347–348
 - flood risks
 - assessments 22–23, 214–215, 215
 - social vulnerability 445
 - inundation
 - expected annual damage 444–445

- expected annual probability 444, 446–447, 450
 - land-use in 215
 - Northern Ireland 246, 246
 - populations
 - changes in 218, 444, 445
 - flooding risk exposure 444, 448–449, 451
 - WM/NE/LS/GS 442–443, 445
 - reversion to 469–470
 - storm surge vulnerability 139
 - urbanisation 7, 69, 497–498
 - WM/NE/LS/GS population vulnerability 216, 217, 218
- fluvial systems
 - see also* estuaries; rivers
 - driver impacts 197
 - ecosystems within 34–35
 - modulation of flow 31
 - morphological changes within 33–34
- forecasting
 - flood events 343–344, 351
 - funding 345
 - governance 345
 - information dissemination 343–345
 - responses 344–345
- Foresight Futures Project
 - costs of implementing 436
 - flood risk management, responses 437–440
 - methodology 13, 14
 - scenario-based approach 9–10, 21
 - socio-economic scenarios 20–22, 20
 - sociological aspects 100–102, 101
 - structural responses, cost estimates 441
 - target defence condition grades 435
 - target standards of protection 433–434, 436, 492–494
 - uncertainties within 26–27
- future investments, coastal defences 288–289, 289
- Geographical Information System (GIS) 5
 - geomorphological engineering, coastal defences 402–403
- glacial sediments, coastal erosion 275, 275
- global sustainability scenario
 - see also* Foresight Futures Project
 - coastal defence responses 405, 406
 - cooperation 352
 - environmental impact 38–40, 41, 95–96
 - flood event management 352
 - flood risks
 - management 384
 - reduction 422–423
 - future flood risks 78–79, 191–193, 216
 - summaries 21–22
- governance
 - catchment storage 307
 - definitions 475–477
 - flood events 345, 485
 - flood losses 486
 - flood risk management
 - costs of 480–482, 481
 - response mechanisms 501–503
 - rivers 382, 486
 - framework of 479–480, 480
 - history 478–479
 - infiltration 302–303
 - response portfolios 484
 - rivers, conveyance 312
 - rural land management 316–317, 316, 484
 - urbanisation 484–485
 - WM/NE/LS/GS 414–416, 477–478
 - policy response themes 415–416, 484–485
- greenhouse gas emissions, future 18, 18
- greenspaces, in flood management 323, 470
- groundwater
 - aquifers 177, 178
 - definitions 174
 - flooding 50, 176
 - future uncertainties 179
 - intra-urban flood management 325–326
 - WM/NE/LS/GS 337
 - recharge 174, 176–177, 177
 - rising levels 177, 179, 179
 - trends in water level 174, 175, 176
- hard surface controls, urban flood management 323
- hard-rock cliffs, erosion 277, 277
- hillslopes
 - connectivity management 312–313
 - conveyance, slowing 311–312
- household expenditure, WM/NE/LS/GS 122
- housing development *see* urbanisation
- human behaviour, Scottish drivers 240–241
- Humber Estuary Shoreline Management Plan 401
- impoundments, flood management 306–307
- industrial losses
 - potential risk uncertainty 128
 - WM/NE/LS/GS 119–121, 127
- infiltration
 - drainage, groundwater table levels 325–326
 - governance 302–303
 - management 303, 304
 - and runoff 298–299
 - sustainability 303
- insurance *see* flood insurance
- intertidal areas
 - reduction 31–32
 - sedimentary balance 35–36

- intra-urban flood management
 - area development 336
 - building design/development 321–322, 335
 - cost per property
 - coincident flooding 331
 - expected annual damage 329–330
 - definitions 320–321
 - environmental implications 470–471
 - extreme event management 324–325
 - financing 323
 - greenspace promotion 323, 470
 - groundwater control 325–326, 338
 - hard surface controls 323
 - rainfall-runoff measures 324–325
 - regional 324
 - response measures
 - annual costs 331–332, 332
 - sustainability assessments 334–335, 335–338
 - uncertainties 332–333
 - WM/NE/LS/GS 333
 - sewer systems 328
 - WM/NE/LS/GS 338
 - source control 336
 - storage
 - above-ground 326, 327
 - below-ground 326–327
 - WM/NE/LS/GS 337
 - sustainability, flood risk management
 - responses 463–467
- inundation
 - floodplains
 - expected annual damage 444–445
 - expected annual probability 444, 446–447, 450
- land drainage, and agriculture 251, 300–301
- land movements, and sea levels 133–134
- land values, and coastal erosion 290
- local stewardship scenario
 - see also* Foresight Futures Project
 - coastal defence responses 405, 406
 - environmental impact 38–40, 95–96
 - flood event management 353
 - flood risks 384, 422–423
 - future flood risks 78–79, 191–193, 216
 - summaries 21–22
- mapping, flood risks 343
- micro-morphology, and conveyance 90–91
- morphological protection
 - coastal defences 402–404
 - sustainability 408–409
- morphology
 - coastal 143–146, 235–236
 - and coastal flooding 146
 - flood risks 82
 - modified estuarine 272–273, 273
 - river channel changes 83, 96–97, 97, 98
- muddy floods 180, 181
 - driver interactions 181–182, 181
 - factors affecting 180–181
 - future uncertainties 182
 - rural land management 304–305
- mudflats, inundations 36
- national enterprise scenario
 - see also* Foresight Futures Project
 - coastal defence responses 405, 406
 - environmental impact 38–40, 95–96
 - flood event management 351–352
 - flood risks 384, 421–423
 - future flood risks 78–79, 191–193, 216
 - summaries 21–22
- Northern Ireland
 - agriculture 250–251
 - coasts
 - defences 247–248, 260, 394
 - erosion 259–260
 - flooding 247–248, 260–261
 - flood alleviation benefits 262
 - flood management authorities 244, 248–250
 - flood return periods 256–258, 257
 - flood risks 246–247, 248, 260, 261, 262–263
 - flooding areas 244, 245
 - floodplains 246, 246
 - housing development 251–252
 - planning services 250, 251–252
 - precipitation changes 252–253, 253, 254
 - predicted warming 253–254
 - relief 244, 245
 - rivers 246–247, 246, 255–256, 258
 - sea level rise 258–259
 - soil types 256
 - storm surges 259
- nuclear power stations, coastal erosion 278, 278, 291–292
- pathways, definitions 16
- planning
 - for flood reduction 363–364
 - controls 364–366
 - land-use conflicts 124–126
 - services
 - Northern Ireland 250, 251–252
 - Scotland 237
 - urbanisation 167
- pluvial flooding, urban 152
- policy response themes, governance, WM/NE/LS/GS 415–416, 484–485
- ponds, bunds and ditches, as runoff storage 306
- population
 - mobility and land-use 123–124, 124
 - urbanisation 125–126
 - WM/NE/LS/GS vulnerability 216, 217, 218, 220

- precipitation
 changes
 future 19, 51, 53–55, 164
 Northern Ireland 252–253, 253, 254
 Scotland 228–230
 as flooding driver 49–50, 51, 152
 high intensity 54
 property, WM/NE/LS/GS expected annual
 damage 452–453, 454
 public attitudes
 as drivers 190
 flood risks 102–103
 and preferences 106–108
 and risk perception 108, 110–112, 111
- rainfall
 extreme 182–183
 runoff measures 324–325
 urban flooding 152, 322
- receptors, definitions 16
- reclaimed land, coastal erosion 278, 278
- recreation land values 468
- renewable energy production, coastal 396,
 398–399, 410–411
- responses 16
 to flood risks 25–26
- risk analysis 8–9
- risk assessments 106
 floods 22–23, 23
 sociological perspectives 101, 101
 stakeholder attitudes 104
 urban flooding 23, 157–158, 161–162,
 163, 164–165
- risk estimates, flooding systems 17, 17
- risk management strategies
 adoption 8
 integrated management through 10–11
- risk perception and awareness 483
 public attitudes to 108, 110–112, 111
- river conveyance 89–93
 altering
 interactions 378
 objectives 377–378
 sustainability 386, 387
 definitions 89
 effective bed roughness 90–91
 governance 312
 hillslope, slowing 311–312
 management
 and catchment storage 313–314
 uncertainties 314–315
 micro-morphology and 90–91
 reducing 312
 vegetation and 89–90
 WM/NE/LS/GS flood increases 92–93
- river defences
 interactions 381
 Northern Ireland 247
 objectives 380–381
- river engineering responses 376, 390
 sustainability assessments 386–387,
 387–389
 WM/NE/LS/GS 377
- River Thames Windsor and Maidenhead
 flood relief scheme 70, 378
- rivers
see also fluvial systems
 alluvial channels 86–87, 86
 bank erosion 301
 defences 380–381
 interactions 381
 sustainability 389, 389
 effective bed roughness 90–91
 flood risk management 381–382
 costs 382–383
 governance 382
 proportionate responses 383–384
 WM/NE/LS/GS attitudes 384
 flood risks
 future increases 384–385
 governance 486
 WM/NE/LS/GS multipliers 385–386
 flood storage
 interactions 379
 objectives 378–379
 sustainability 386–387, 388
 flood-water transfer
 interactions 380
 objectives 379–380
 sustainability 387, 388
 management policies 93
 morphology 82–83
 changes 83, 96–97, 97, 98
 realignment 312
 restoration 312
 Scottish processes 232–233, 239–241
 sediment supply variables 83–85, 98
 uncertainties 87, 98
 WM/NE/LS/GS impacts 88
- runoff
 due to livestock 300
 farm management practices 299–300
 and infiltration 298–299
- rural land management 65
see also agriculture
 and flood defences, traditional
 315–316
 flood risks responses 317
 governance, options 316–317, 316
 hillslope conveyance, slowing 311–312
 infiltration 298–299
 governance 302–303
 muddy floods 304–305
 on-farm practices 299
 responses 298
 riparian conveyance, reducing 312
 rivers 312
 sustainability 303–304, 313

- rural land-use
 - see also* agriculture
 - afforestation 67
 - arable 66–67
 - coastal grazing marshes 32, 36, 40, 41
 - driver interactions 75, 76, 77
 - floodplain 67–68
 - runoff pathways 65
 - Scotland 231–232
 - soil structure 65–66
 - upland 66
- saltmarshes
 - inundations 36
 - loss of 40–41, 273
 - regeneration 398
- scenario-based approach, Foresight Project 9–10
- scenarios, definitions 16
- science and technology, as drivers 190–191
- Scotland
 - agricultural impacts 232
 - climate change driver 239–240
 - coastal process drivers 240–241
 - coasts
 - cells 235–236, 235
 - defences 394
 - morphology 235–236
 - driver rankings 239–242
 - flood management
 - authorities 227–228
 - legislation 233, 236–237
 - human behaviour drivers 240–241
 - land-use drivers 239–240
 - planning applications 237
 - precipitation changes 228–230, 239
 - public flooding awareness 237–238
 - relative sea-level rise 234
 - rivers 232–233, 239–241
 - rural land-use management 231–232
 - snowmelt changes 230
 - socio-economic drivers 238–241
 - storm surges 233–234
 - sustainable flood management 237
 - temperature changes 230
 - urban drainage 237
 - urbanisation 230–231
 - WM/NE/LS/GS driver rankings 239–242
 - WM/NE/LS/GS flood scenario 230
- sea levels
 - and climate change 5, 19, 287
 - and coastal erosion 285–287
 - and coastal morphology 144–145
 - current trends 132–135, 134, 135
 - future trends 133–134, 136–137
 - and land movements 133–134
 - Northern Ireland 258–259
 - relative rises in 234
 - storm surges 136–137, 138, 140
 - wave actions 140–143, 141
- sediment providers, cliff erosion 272
- sedimentary balance, intertidal areas 35–36
- sewers
 - below-ground storage in 326–327
 - combined 328
 - dynamic management of 329
 - flooding by, prevention 328–329
 - groundwater infiltration 154
 - sediments in 154–155
 - separate 328
 - urban flooding and 151, 152–153
 - WM/NE/LS/GS projected losses 165–166
- shingle beaches
 - coastal erosion 276, 276
 - loss of 33
 - nourishment 397, 398
- shorelines
 - changes 280–284, 281, 283
 - management, impacts of 32–33
- social justice, flooding risk reduction 471–472
- social support, flood victims 119
- socio-economic impacts
 - domestic losses 119–120, 121, 123
 - Foresight Futures Project 20–22, 20
 - industrial losses 119–121
 - regional uncertainties 129–130
 - Scotland
 - drivers 240–241
 - flooding 238–241
- sociological aspects
 - communal solidarity 117
 - cultural theory types 110–111, 111
 - floods 212
 - intangible losses 118–119, 118
 - risk impact 116–117
 - low income groups 117
 - public attitudes 106–108, 110–112, 111
 - risk attitudes 100–102, 101
 - world markets scenario 350–351
- soil structure
 - compaction 67, 300
 - flooding impact 73–75
 - rural land-use 65–66
- soil types, Northern Ireland 256
- sources, definitions 16
- stakeholders
 - as drivers 102, 103–106
 - future flood risks 112–114
 - insurance sector as 103
 - motivation of 104, 105
 - public preferences 106–108
 - regulatory influences 103
 - risk attitudes 104
 - urban flooding 155–156
- Standards of Protection (SoP), flood defences 211

- state aid/compensation, flood losses 362
- storm surges
 - causes 136–137, 268
 - and climate change 287
 - estuarine barriers 395, 395
 - floodplain vulnerability 139
 - future projections 137, 138, 140
 - Northern Ireland 259
 - Scotland 233–234
- stormwater
 - domestic storage 322
 - drainage systems 68
 - flooding from 151
- stream back-up, urban flooding 153
- surges *see* storm surges
- sustainability
 - above-ground storage 327
 - analysis, flood risk reduction responses 426–429, 429
 - catchment storage 307–308
 - coastal defence response groups 408–409
 - definitions 461
 - domestic stormwater storage 322
 - flood event management 353–354, 354–356, 357
 - flood reduction 372–373, 372
 - flood risk responses
 - coastal zones 462–463, 465–466
 - cost effectiveness 465–468
 - intra-urban zones 463–466
 - future 461–462, 472–473
 - metrics 426, 427–428, 429
 - river conveyance, altering 386, 387
 - rivers
 - defences 389, 389
 - flood storage 386–387, 388
 - flood-water transfer 387, 388
 - rural land management 303–304, 313
 - urban drainage management 325, 334–335
 - WM/NE/LS/GS 335–338
- target defence condition grades, WM/NE/LS/GS 435
- target standards of protection, WM/NE/LS/GS 433–434, 436, 492–494
- taxation, flood loss relief 481–482, 481
- temperatures
 - driver impact 197
 - and flood risks 50
 - and flooding frequencies 55
 - future global rises 19
 - trends
 - Northern Ireland 252, 253–254
 - Scotland 230
- Thames Barrier 395, 395
- transport implications, coastal defence re-alignments 400–401
- uncertainties
 - assessments of 26
 - cascades 60–61
 - conveyance management 314–315
 - flood event management 357
 - flood risks, reduction responses 423–426
 - intra-urban flood risks, response measures 332–333
 - types of 59–60
 - water retention, catchment storage 309–311
 - within Foresight Futures Project 26–27
 - Wynne classification 315–316, 423–424
- uncertainty analysis 185–186, 199
- United Kingdom Climate Impact Programme (UKCIP) 7
- urban flooding
 - see also* intra-urban flood management
 - causes 320–321
 - and climate change 155
 - driver identification 156–157
 - flood waves 152
 - increasing potential 123
 - rainwater 152
 - responses 162, 163, 164
 - risk assessments 23, 157–158, 161–162, 163, 164–165
 - risk reduction responses 418–419
 - sewer inadequacies 151, 152–153
 - spatial scales 150, 150
 - stakeholder attitudes 155–156
 - stream back-up 153
 - surface runoff 151–152
 - and urbanisation 154
 - WM/NE/LS/GS
 - annual damages 166–167
 - driver ranking 158–159, 161
 - driver uncertainty 160–161
- urban infrastructure, definitions 126–127
- urban land-use 64
 - average run off 69
 - culverting and 154
 - driver interactions 75, 76, 77
 - driver uncertainty 69–70
 - flood detention measures 68–69
 - floodplains 69
 - new developments 237
 - and planning conflicts 124–126
 - and population mobility 123–124, 124
 - storm water drainage systems 68, 150–151
- urbanisation
 - floodplains 7, 69, 497–498
 - governance 484–485
 - Northern Ireland 251–252
 - planned 167
 - Scotland 230–231
 - and surface run-off 154
 - WM/NE/LS/GS risk changes 167–168

- washlands
 - conversion to 308
 - as storage areas 31, 306
- water recycling systems 154
- water table depths, agricultural areas 72–73
- water-level control structures
 - flood fighting 345–347
 - responsibility for 345, 347
- waves
 - action 140–141
 - coastal erosion 268
 - definitions 140
 - future changes 142–143, 287
 - heights 141–142, 141
 - urban flood 152
- wetlands
 - conversion to 308
 - environmental economics 42–43, 42
 - NGO funding 308
 - as storage areas 306
- world markets scenario
 - see also* Foresight Futures Project
 - coastal defence responses 404–406
 - environmental impact 38–40, 95–96
 - flood event management 350–351
 - flood risks 384, 421–422
 - future flood risks 78–79, 191–193, 216
 - high/low emissions scenarios 223, 224
 - sociological aspects 350–351
 - summaries 21–22
- Wynne classification of uncertainty
 - 315–316, 423–424