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Chapter 1

Introduction and methodology

This chapter introduces the Foresight Flood and Coastal Defence project and places it within the context of current flood risks within the UK. It then explains how the work reported here fits into that project.

The chapter outlines the technical methodology and the models used and, in particular, it explains how different climate and socioeconomic scenarios have been used to assess possible UK flood risk between 2030 and 2100. Finally it explains how future uncertainty has been addressed.

1.1 The Foresight project

The Foresight Flood and Coastal Defence project set out to produce a long-term vision for the future of flood and coastal defence in the UK. This vision, while taking account of the many uncertainties such as the future extent of climate change, provides a robust analysis to inform policy development.

The Office of Science and Technology (OST) initiated the Flood and Coastal Defence (FCD) project because of growing awareness that flooding poses an increasing threat to the economic and social activity of the UK. The rising values of buildings and their contents mean that even the prevailing intensity of flooding could impose greater economic and financial burdens in the future. Climate change will exacerbate the risk still further.

The objectives of the project are to:

- Identify and assess the relative importance of the threats that need to be taken into account in long-term planning on flood and coastal defence.
- Construct a set of risk-based scenarios taking those factors into account over a 30-100 year timescale and addressing social, economic and environmental issues.
- Provide an overview of the responses that are available to us and the key issues that determine those responses.
- Inform policy and its delivery.

In addition, the work seeks to:

- Identify implications for the future skills base.
- Identify knowledge and technologies that might transfer from other sectors.
- Inform long-term needs for research on flood and coastal defence.
- Inform public understanding and the debate on flood and coastal defence.
- Promote an effective and enduring dialogue between the science base and stakeholders, and between those with an interest in flood and coastal defence.

The project is broad in scope. Geographically, it covers all of the UK: England, Scotland, Wales and Northern Ireland. It also considers river, coastal and estuarial flooding, local flooding due to heavy rainfall, and coastal erosion. Finally, it takes a holistic view of future flood risk by considering economic, social and environmental impacts.

The project proceeded in three phases:

Phase 1 – scoped the problems of flooding and coastal erosion and developed a methodology for the analysis in subsequent phases.

Phase 2 – analysed drivers and potential impacts of future flood risk under a simple baseline assumption that existing flood management policies continue unchanged. This assumption enables existing policies to be assessed against future risks, and identification of useful changes.

Phase 3 – analysed potential changes to flood management and related policies that would improve the management of future flood risk.

This report describes Phase 2 of the project. Phase 3 is reported in Volume II.

The main tasks of Phase 2 and their coverage in this report are as follows:

- Identify and analyse the processes that will drive future flood risk and compare their influence – Chapter 2 considers drivers at catchment scale, and Chapter 3 covers local or intra-urban scales.
- Establish the possible scale and nature of future flooding risks. Chapters 4 and 5 address economic impacts and Chapter 7 environmental impacts.
- Assess risks from coastal erosion – Chapter 6.
- Summarise the Phase 2 findings and assess their implications – Chapter 9.

In performing the above analysis, the work of Phase 2 provides the basis for identification and analysis of policy responses in Phase 3.

The remainder of this chapter introduces the concepts and terminology that are used in Phase 2, and outlines the analysis methodology.

1.2 Current flood risks and costs

This section sets the scene for the subsequent analysis of future risks by drawing together available information on present-day flood risks and flood-defence costs in the UK.

Current risks and flood-defence costs for both fluvial and coastal flooding, erosion, and intra-urban flooding (i.e. flooding arising within the urban area) are summarised in Table 1.1.

Table 1.1 **Summary of current risks of flooding and flood defence costs in the UK**

	People at risk (million)	Properties at risk	Value of property and agricultural land at risk (£ billion)	Expected Annual Damage (£ million)	Flood-defence costs 2003–04 (£ million)
Fluvial and coastal flooding					
England and Wales	4.5	1,740,000	215	1,040	439
Scotland		180,000		32 (fluvial only)	14
Northern Ireland		45,000		16 (fluvial only)	11
Coastal erosion					
England and Wales				14	
Intra-urban flooding					
All UK		80,000		270	320
Total		**2,045,000**		**1,400**	**800**

(Totals have been rounded)

The current flood risks for England and Wales are taken from Defra (2002). No separate figures are available from Defra's study of flooding within the boundary of the Welsh Assembly Government. An indication of damages in Wales may be gained from the Environmental Agency's record of damages for the Welsh region of £111 million. No damage figures of comparable reliability are available for Scotland and Northern Ireland but the approximate figures quoted give some idea of the relative magnitudes of the risks there.

The figures for intra-urban flood risk are explained in Chapter 5 and it should be noted that they use a wider definition of properties at risk than the registers of Ofwat, the water industry regulator. There may be some double-counting of properties at risk from fluvial/coastal flooding and intra-urban flooding.

To compare the figures with recent records, the total economic damage estimated in England and Wales during the widespread flooding of Autumn 2000 has been put at £787 million, affecting over 11,000 properties and infrastructure including 1,650 properties in Wales (Penning-Rowsell and Chatterton 2001). In Scotland the Strathclyde floods centring on Glasgow in 1994 resulted in over £100 million damages.

Estimated flood-defence costs covering both capital and maintenance for the UK are based on publicly available information.

1.3 The analytic framework used

1.3.1 Defining the flooding system

The mechanisms and impacts of flooding involve many aspects of the physical environment as well as economic and social systems. These diverse aspects are part of an interconnected flooding system.

The present work has performed an assessment of flood risk that is both comprehensive and integrated. A broad definition of the flooding system has therefore been used – ‘the flooding system encompasses those physical and organisational systems that influence or are influenced by flooding’ (Hall *et al*. 2003). This definition covers:

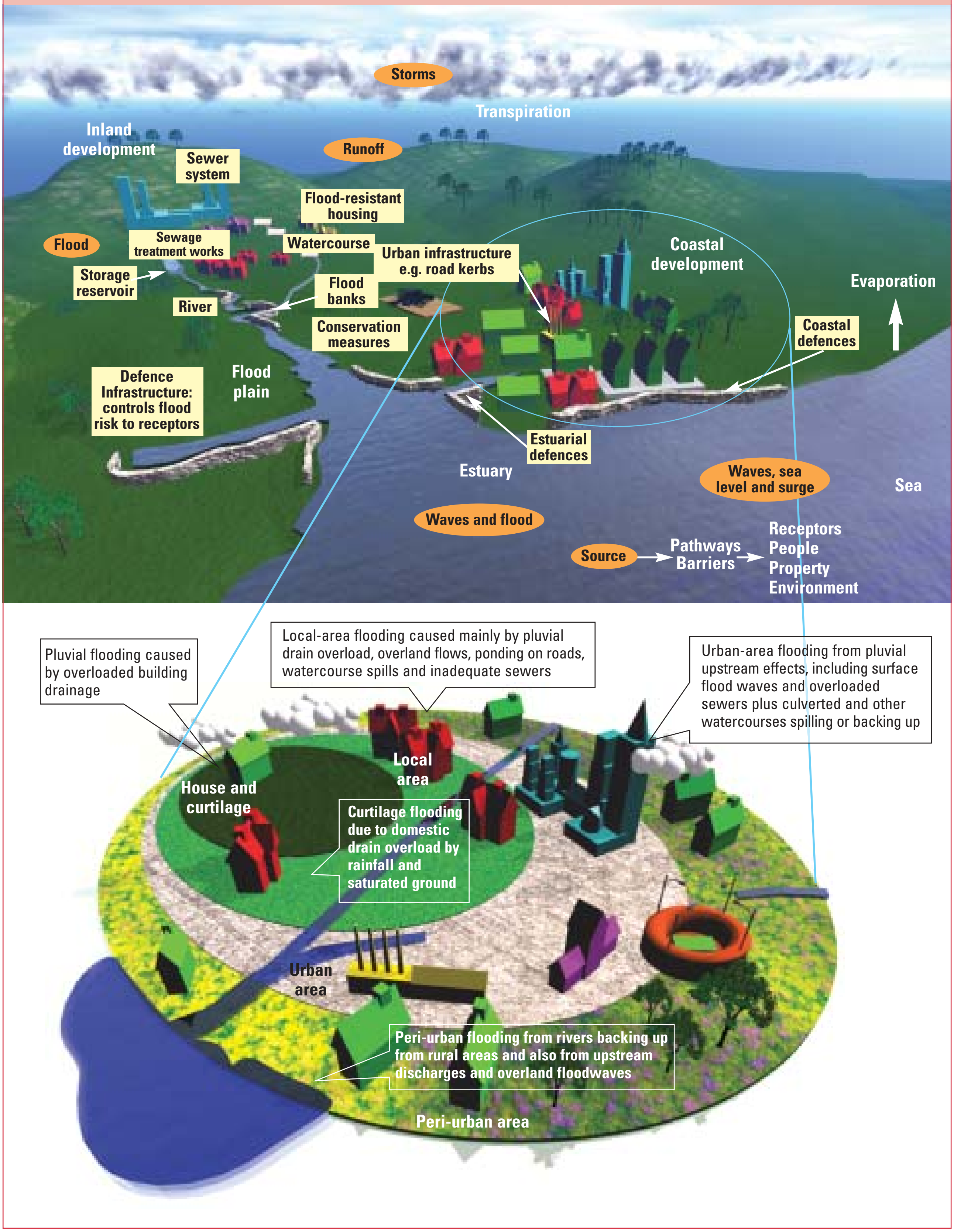
- The physical attributes of the Earth’s surface involved in the water cycle i.e. the processes of rainfall, snow melt and marine storms that lead to fluvial and coastal flooding, runoff from the land, groundwater flows and flood inundation in fluvial floodplains and coastal lowlands.

- The man-made systems of drainage, storage and flood defence that are intended to convey flood discharges and control inundation of floodplains.
- Economic, social and environmental assets in floodplains that flooding affects and/or have an impact on flooding.
- Bodies with a statutory responsibility for managing flood risk. These may be government institutions or other organisations.
- Insurers who provide cover for flood risks.
- Broader stakeholder groups with an interest or role in the impacts – both positive and negative – of flooding and the actions that may be taken to manage flooding.

The flooding system involves a complex array of interconnected hydraulic subsystems that are subjected to precipitation, marine storms and water flows resulting in flooding (see Figure 1.1). These subsystems operate at different scales. At the highest level, fluvial and coastal flooding is caused by weather events at the scale of catchments and their estuarial and coastal equivalents (Chapters 2 and 4 of this report cover the analysis at this scale). The analysis also addresses the impacts of flooding of urban areas (Chapters 3 and 5). At this level, flooding usually results from intense localised rainfall that overwhelms the urban drainage system. While often localised, these intra-urban floods can be very damaging in economic, social and environmental terms.

Dispersed episodes of flooding detached from the floodplain, such as groundwater flooding, have also been considered.

Figure 1.1 **A hydraulic perspective of the physical flooding system, illustrating the nesting of urban systems within the catchment**



1.3.2 Modelling the flooding system

The analysis has used two complementary models of the flooding system:

The Pressure State Impact Response (PSIR) model provides a useful tool for the analysis of the flooding system (Turner *et al.* 1998; Rapport and Friend 1979). In the PSIR model:

- Socioeconomic drivers lead to environmental *pressures*.
- Environmental pressures lead to changes in environmental *state*.
- Environmental and socioeconomic *impacts* are reflected by changes in environmental state.
- Impacts lead to policy *responses* following gains/losses by stakeholders.

However, while the PSIR framework deals with the changes in the flooding system, it does not allow the flooding system to be evaluated in terms of risk. Here the Source-Pathway-Receptor (SPR) model (DETR *et al.* 2000) has been used.

The SPR model provides a well-established framework for environmental risk assessment. In the case of flooding:

- *Sources* are weather events, or sequences of events that may result in flooding (e.g. heavy or sustained rainfall and marine storms).
- *Pathways* are the mechanisms that convey floodwaters that originate as weather events to places where they may impact on receptors. Pathways therefore include fluvial flows in or out of river channels, overland urban flows, coastal processes and failure of fluvial- and sea-defence structures or urban drainage systems.
- *Receptors* are the people, industries and built and natural environments that flooding affects.

Besides the PSIR and SPR models, the analysis also makes use of the concepts of 'drivers' of and 'responses' to flood risk: 'a *driver* is any phenomenon that may change the state of the flooding system'. However, some drivers will be under the control of flood managers, for example, through flood defences or through flood warning systems – these drivers are regarded as potential *responses* to flood risk. Conversely, responses can themselves become drivers in certain circumstances – for example, the use of engineering to control flood risk in a town will affect flood risk downstream and will therefore be a driver of downstream flood risk.

Figure 1.2 **The degree of control for different drivers: drivers towards the right can be used as responses to flood risk**

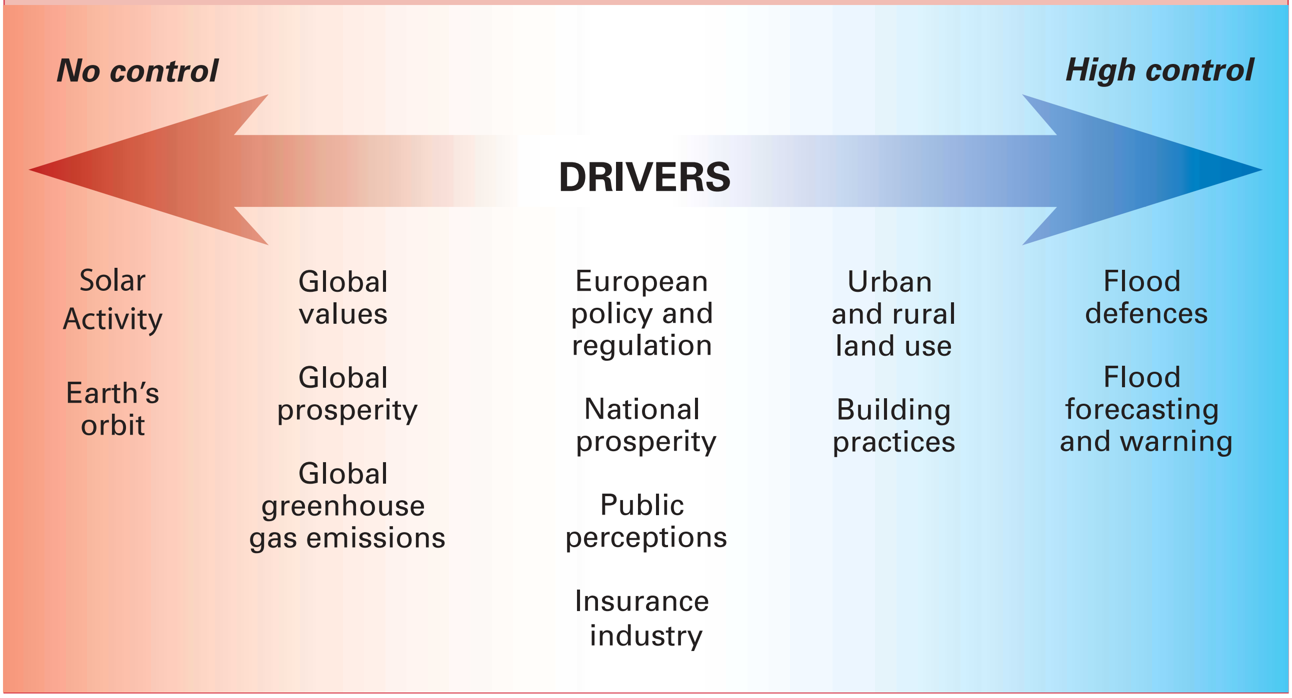
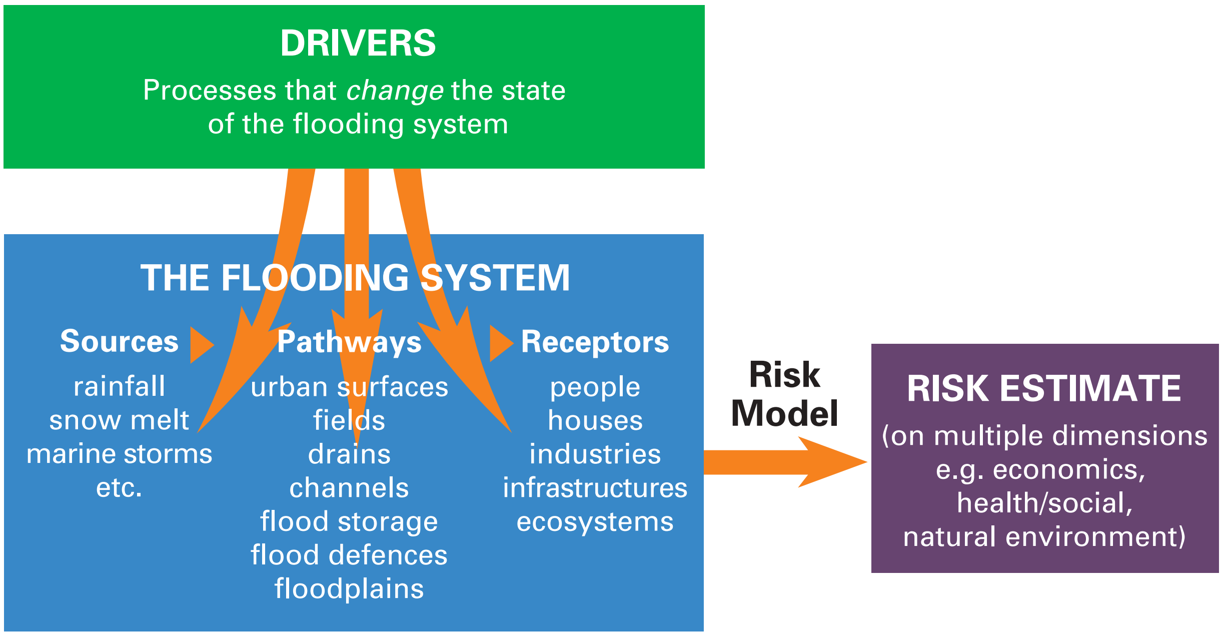


Figure 1.2 sets out a range of drivers of future flood risk and groups them according to their degree of control. For example, the Government has strong control of flood defences, so these appear at the far right. Conversely, it has less power to influence global emissions so that appears more towards the left. Because of the degree of control, the drivers on the right can be most easily used as responses. However, some of the drivers towards the left (such as global emissions) have a large influence on flood risk, and could make a substantial contribution to managing risk if they can be influenced.

The analysis combines the concepts of drivers and responses with the SPR model as follows. The flooding system is characterised in terms of flooding sources, pathways and receptors or a combination of these. Multi-attribute risk measures are used to characterise the behaviour of the flood system with respect to stakeholder values. Future changes in risk (due to the influence of drivers) are assessed by making appropriate changes to state variables and estimating the consequent changes in risk.

Figure 1.3 **The relationship between drivers, the flooding system and flood risk**



There are complex feedbacks in the flooding system. For example, an impact on the environment may alter the flooding pathways, and potentially sources, that then influence future relationships between sources, pathways and receptors. This is particularly important for climate change. Here interactions between the Earth's surface and socioeconomic processes, perhaps leading to wholesale changes in land use, aquatic character and so on, are likely to produce long-term impacts. These interactions may well represent some of the greatest threats and opportunities for flood management in the long term.

Such complex interactions over timescales of decades are not open to conventional quantified risk analysis (IPCC 2000). For this reason the project adopted an approach based on scenarios, a well-established way of considering alternative futures (see Section 1.4).

Definitions

Flooding system:	All physical and human systems that cause, influence, or are influenced by, flooding.
Sources:	Weather-related phenomena (rainfall, marine storms, snow melt etc.) that generate water that could cause flooding.
Pathways:	Mechanisms by which water travels from its source to places where it may affect receptors (e.g. runoff, fluvial flows, sea defence overtopping, floodplain inundation).
Receptors:	People, industries and built and natural environments that flooding can affect.
Flood risk:	A combination of the probability and consequences of flooding. To estimate flood risk requires a system model which may be conceptual or quantified, that includes sources, pathways and receptors.
Drivers:	Phenomena that may *change the state* of the flooding system, such as climate change, urbanisation or changing agricultural practices. A driver may change *sources, pathways, receptors* or a combination of them.
Responses:	Changes to the flooding system that are implemented to reduce flood risk.
Scenario:	A consistent storyline embracing a set of changes to the flooding system.

1.3.3 Handling localised urban flooding

Urban flooding differs in a number of important ways from flooding at the catchment level. In broad-scale analysis, it is assumed that drivers affect flood risk at the scale of catchments and their estuarial and coastal equivalents. In this case, the urban receptor areas can be thought of merely in terms of their building types and locations.

Within the urban area, additional drivers and risks are generated by the finer-scale mechanisms of flooding in the intra-urban zone (Figure 1.1). Drivers within urban areas essentially relate, not to invasion of the urban zone by external water, but to pluvial flooding from shorter-duration rainfall events acting through flooding pathways within the urban area. There may also be further risks associated with external invasion which are not covered in the high-level analysis. For example, external floodwater could ruin electromechanical equipment and put sewerage-system pumping stations out of action.

If the two types of flood event were independent and had a low probability, the chances of them coinciding would be very small, perhaps negligible. They could then be treated as mutually exclusive and therefore additive. In reality, the picture is likely to be more complicated, but it is nonetheless a reasonable assumption for the Foresight project. Thus to first order approximation, we sum both sets of damages at the national level in the quantitative analysis.

1.4 Using scenarios to address complexity and uncertainty

Scenarios are a recognised technique for investigating long-term futures where there are many complex and interacting variables, and where the future is very uncertain. The extreme complexity of the evolving flooding system and uncertainties surrounding greenhouse gas emissions make their use ideal for informing flood-risk assessment and in informing the development of long-term policies.

The idea is to construct a number of alternative future scenarios and to assess the size and nature of flood risk that could result for each. In so doing, it is possible to gain a broad appreciation of the scale of future risks that may need to be addressed and the degree of flexibility and adaptability that is ideally needed in future flood-management policies.

In this work, two different types of scenario have been combined:

- Climate-change projections based on *emissions scenarios* – climate change is a key driver relating to the flooding 'source' variables in the SPR model.
- *Socioeconomic scenarios* – these provide the context in which flood-management policy and practice will be enacted, and relate to the extent to which flooding may affect society.

This combination of scenario type is important: climate change will tend to affect the probability of a flood occurring, whereas the socioeconomic factors will largely determine the cost of the resulting damage. Both are needed to provide a complete picture of future flood risk.

Four different such combinations of climate and socioeconomic scenario were first used to assess the future flood risk under the initial baseline assumption that flood-management policies continue unchanged into the future. There is no casual link between the socioeconomic and climate change scenarios considered. However, it was not possible to run a scenario for all socioeconomic and climate change combinations. So we have chosen four combinations which allow us to explore a reasonable range of future possibilities. We have also considered a fifth combination to assess the contribution of climate change to changes in flood risk.

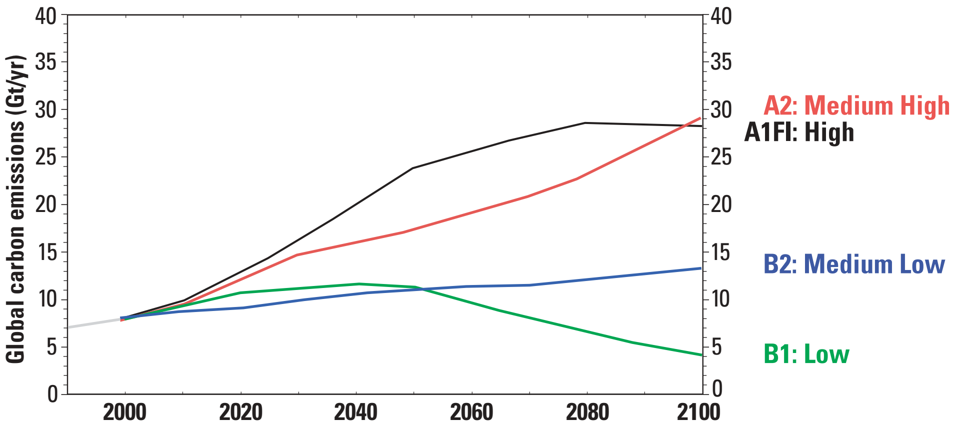
1.4.1 Time slices in scenarios analysis

The climate naturally shows a great deal of variability. To separate climate change from this natural variability, it is customary to average results from climate models over many years. The UK Climate Impacts Programme (UKCIP) published climate scenarios for three time slices – 2020s, 2050s and 2080s. To be consistent with the UKCIP approach, and to make use of the widely accepted UKCIP scenarios, the Foresight project focused on the 2050s and 2080s.

1.4.2 Scenarios of climate change

The analysis of flood risk was based on climate scenarios from the report of the UK Climate Impacts Programme, UKCIP02 (Hulme *et al*. 2002). These include four scenarios for emissions into the atmosphere of carbon dioxide: Low emissions, Medium Low emissions, Medium High emissions and High emissions. The scenarios encompass a range of global greenhouse gas emissions and changes in global mean temperature (see Figures 1.4 and 1.5).

Figure 1.4 **The project employed four scenarios for emissions of carbon dioxide: Low emissions, Medium Low emissions, Medium High emissions and High emissions. These come from UKCIP02, the 2002 report of the UK Climate Impacts Programme**



The scenarios in UKCIP02 lead to several predictions relevant to flooding:

- Annual average precipitation across the UK may decrease by between 0% and 15% by the 2080s, depending on the scenario.
- The seasonal distribution of precipitation will change. Winters will become wetter and summers drier. The biggest relative changes will be in the south and east. Under the High emissions scenario, winter precipitation in the south-east may increase by up to 30% by the 2080s.
- By the 2080s, the daily precipitation intensities that are experienced once every two years on average may become up to 20% heavier. The scenarios give no guidance on the effects of climate change on more extreme precipitation events.
- By the 2080s, depending on scenario, relative sea level may be between 2cm below and 58cm above the current level in western Scotland and between 26 and 86cm above the current level in south-east England.
- For some coastal locations, a water level that at present has a 2% annual probability of occurrence may have a 33% annual probability by the 2080s for Medium High emissions.

The choice of these four emissions scenarios provides a reasonable spread of possible future climate change against which to assess future flood risk. However, the scenarios do not necessarily include the most extreme possibilities. For example, possible errors in the climate modelling and uncertainties in the level of future emissions could mean that the future climate could be more or less extreme than the four scenarios used here (see Section 1.5.1; also Jenkins and Lowe 2003).

1.4.3 Socioeconomic scenarios

The Foresight Futures socioeconomic scenarios are intended to suggest possible long-term futures (SPRU *et al.* (1999); OST 2002). These scenarios explore directions in which social, economic and technological changes may evolve in coming decades (see Figure 1.6). The four Foresight Futures that occupy this grid are summarised in Tables 1.2 and 1.3. Further estimates of future socioeconomic parameters are available from OST (2002).

Figure 1.5 **Annual global-average surface air temperature relative to 1961–1990 average (grey). The dotted green and black curves represent the full IPCC range of global temperature change when both emissions uncertainties and model uncertainties are considered**

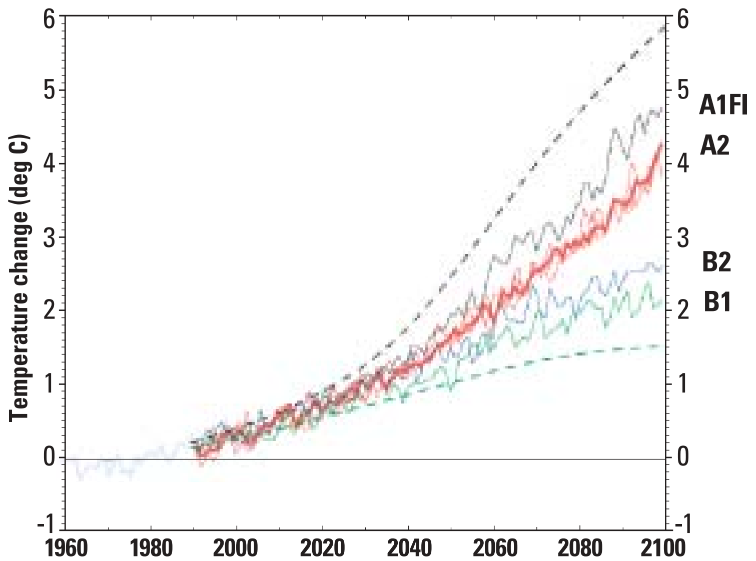


Figure 1.6 **Foresight Futures**

In its assessment of flood risk, the project used scenarios of socioeconomic futures. The vertical dimension shows the system of governance, ranging from autonomy, where power remains at the regional/national level, to interdependence, where power increasingly moves to other institutions, for example, the European Union. The horizontal dimension shows social values, ranging from individualistic values to community-oriented values (SPRU *et al.* (1999); OST 2002).

Table 1.2 **Summary of Foresight Futures (OST 2002)**

	World Markets	National Enterprise	Local Stewardship	Global Sustainability
Social values	Internationalist, libertarian	Nationalist, individualist	Localist, co-operative	Internationalist, communitarian
Governance structures	Weak, dispersed, consultative	Weak, national, closed	Strong, local, participative	Strong, co-ordinated, consultative
Role of policy	Minimal, enabling markets	State-centred, market regulation to protect key sectors	Interventionist, social and environmental	Corporatist, political, social and environmental goals
Economic development	High growth, high innovation, capital productivity	Medium-low growth, low maintenance innovation, economy	Low growth, low innovation, modular and sustainable	Medium-high growth, high innovation, resource productivity
Structural change	Rapid, towards services	More stable economic structure	Moderate, towards regional systems	Fast, towards services
Fast-growing sectors	Health & leisure, media & information, financial services, biotechnology, nanotechnology	Private health and education, domestic and personal services, tourism, retailing, defence	Small-scale manufacturing, food and organic farming, local services	Education and training, large systems engineering, new and renewable energy, Information services
Declining sectors	Manufacturing, agriculture	Public services, civil engineering	Retailing, tourism, financial services	Fossil-fuel energy, traditional manufacturing
Unemployment	Medium-low	Medium-high	Medium-low (large voluntary sector)	Low
Income	High	Medium-low	Low	Medium-high
Equity	Strong decline	Decline	Strong improvement	Improvement

Table 1.3 **Snapshot statistics for socioeconomic scenarios for the 2050s (UKCIP 2000)**

	Today	World Markets	National Enterprise	Local Stewardship	Global Sustainability
GDP growth per year (%)	2.5	3.5	2	1.25	2.75
Total investment – % of GDP	19	22	18	16	20
Agricultural activity (% of total activity)	2	1	2	3	1.5
Newly developed land (hectares per year)	6,500	6,000	4,500	1,000	3,000
Primary energy consumption (million tonnes of oil equivalent)	230	280	270	230	230
Primary energy consumption (% average change per year)		+1.7	+1.5	+0.1	+0.1

1.4.4 Combining the climate change and socioeconomic scenarios

There is no direct or unique correspondence between the UKCIP02 scenarios and the Foresight Futures 2020, not least because the Foresight Futures specifically relate to the UK, whereas the emissions scenarios used in UKCIP02 are *global* emissions scenarios. Table 1.4 details the combinations we used in our analysis.

While these combinations of scenario provide a reasonable spread of futures to assess, other possible combinations are also of interest. In particular, we have also evaluated a fifth scenario in order to consider the possibility of combining a high-growth economy (World Markets) with the Low emissions scenario of UKCIP02. In so doing we have been able to separate the effect of emissions on future flood risk.

Note: in this report, each of the four combined scenarios is referred to by its socioeconomic component – for example World Markets/High emissions is termed 'World Markets' only. Whenever the fifth scenario is mentioned, 'World Markets/Low emissions' is always used to distinguish it.

Table 1.4 **Assumed correspondence between UKCIP02 scenarios and Foresight Futures**

IPCC-SRES	UKCIP02	Foresight Futures 2020	Commentary
A1F1	High emissions	World Markets	Highest national and global growth. No action to limit emissions. Price of fossil fuels may drive development of alternatives in the long term.
A2	Medium High emissions	National Enterprise	Medium-low growth, but with no action to limit emissions. Increasing and unregulated emissions from newly industrialised countries.
B2	Medium Low emissions	Local Stewardship	Low growth. Low consumption. However, less effective international action. Low innovation.
B1	Low emissions	Global Sustainability	Medium-high growth, but low primary energy consumption. High emphasis on international action for environmental goals (e.g. greenhouse gas emissions control). Innovation of new and renewable energy sources.

1.4.5 Flood management within the scenarios

Future flood risk will depend heavily on future flood-management policies. So in order to evaluate flood risk for the different future scenarios, assumptions must first be made about future flood management.

In Phase 2 of the project which is reported in this Volume, a simple 'baseline assumption' was used. The project used the current pattern of expenditure and technical approach as the baseline policy for flood management for all of the future scenarios under consideration. It is not suggested that this is the most likely (or effective) way in which flood management will evolve. However, it does enable an assessment to be made of the extent to which current policies can cope with possible future risks. In so doing, the results inform the work of Phase 3 (reported in Volume II), which considers where changes in long-term policies could be most usefully considered.

1.5 Uncertainty

The Foresight Flood and Coastal Defence Project is the first integrated analysis of drivers and impacts of flood risk in the UK over a time-scale of 30 to 100 years. The uncertainties in this analysis are considerable due to:

- Uncertainties in scenarios of greenhouse gas emissions and socioeconomic change.
- Uncertainties in model simulations of climate and flood risk.
- Uncertainties in feedbacks between evolving flood risks and the ways in which society and the environment will respond and adapt.

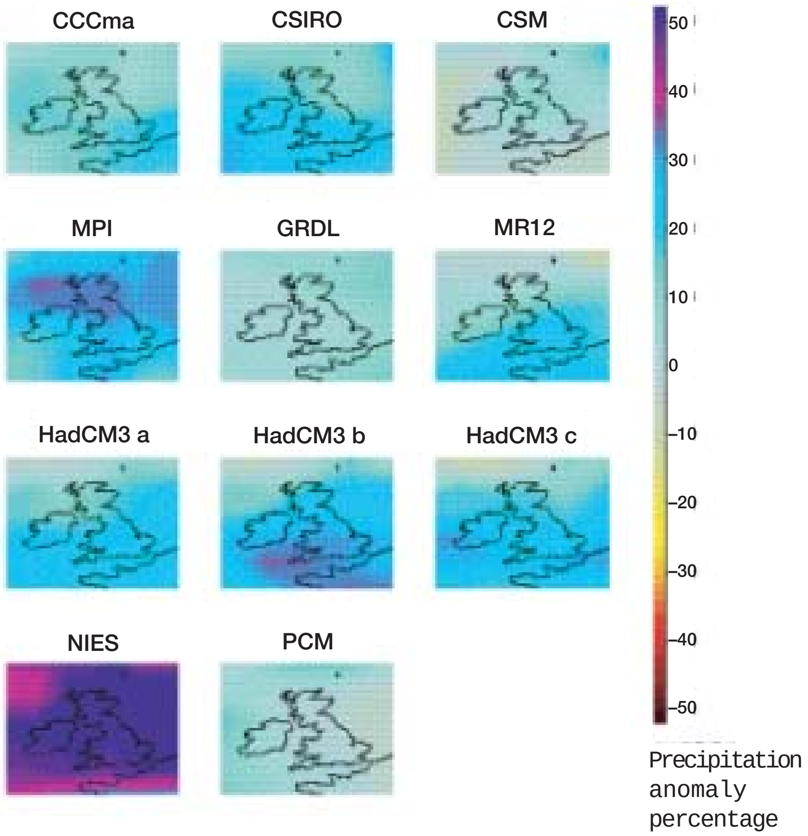
However, uncertainty about the future is inevitable. The challenge is to develop policies that are flexible and can be adapted to an evolving future.

As explained above, uncertainties in emissions of greenhouse gases and socioeconomic change have been addressed by considering five diverse future scenarios. This enables the range of the uncertainty to be sampled.

1.5.1 Uncertainty in climate models

Until the 2050s, uncertainties in climate models, reflected in the differences between models, exceed the uncertainties due to alternative emissions scenarios, even for the most ‘stable’ climate indicators such as global mean temperature. This is because future climate is a reflection of past emissions. Changes to emissions now and in the future will not become evident until beyond the 2050s. By the 2080s, when it comes to predictions of global mean temperature, all climate models reflect broadly the same pattern of differences between alternative emissions scenarios.

Figure 1.7 **Climate models predict different patterns of average winter precipitation across the UK. These predictions, simulated by nine global climate models for the 2080s, are for the Medium High emissions scenario in UKCIP02 (Hulme *et al.* 2002).**



There is considerable variation in the degree of confidence with which one can predict different climate variables. UKCIP02 attaches 'High confidence' to predicted temperature increases, winter precipitation increases, snowfall decreases, summer soil-moisture decreases and sea-level rise. Predicted changes in storminess have lower confidence associated with them.

It is possible to predict mean values of variables with much more confidence than extremes. For example, one can be more confident about changes in mean sea level than about single events, such as when sea levels exceed the 'once in 50 years' average during storm events. Moreover, averaging a variable over a longer period gives higher confidence in the predictions. Thus one can predict monthly average rainfall with more confidence than one can forecast hourly average rainfall. Some systems, notably urban drainage systems, respond very rapidly to changes in rainfall, so we need to predict rainfall over durations as short as 10 or 15 minutes. Predictions of the impact of climate change on such short-duration rainfall are very uncertain.

1.5.2 Uncertainty in socioeconomic scenarios

The research reported in this volume indicates that socioeconomic change may have an even greater impact than climate change on flood risk. Yet socioeconomic projections are by their nature less precise than models of physical systems such as the climate. The four Foresight Futures scenarios therefore represent a range of possible socioeconomic futures.

In view of the long-term perspective of this project, it is impossible to assess the probability of each scenario occurring – and indeed, major events such as war could precipitate a change in scenario in the future. Furthermore, the reality may be more extreme than those considered.

1.6 Valuation of flood risks

Analysis of future flood risk has to consider both changes to the *probability* of flooding, for example, due to climate or land-use change, and the *consequences* of flooding. One can evaluate risk on different scales, depending on how one measures the consequences of flooding. The most common measure of flood risk is the expected annual economic impact of flooding to the nation as a whole, often referred to as 'annual average damage' (or Expected Annual Damages – EAD). In our analysis, the following assumptions were made:

- Inflation is excluded.
- Prices were not discounted to present values.
- The distribution and type of assets vary under each scenario. An inventory of assets at risk and their value is projected to the 2050s/2080s for each scenario. This enables us to establish the losses associated with a given depth of flooding, and how this varies between scenarios.
- Provision of government subsidies varies across the scenarios.

It is instructive to consider economic impacts both in absolute terms and also as a proportion of national wealth. Both are valid metrics and both provide different insights into the consequences of flooding and the resulting 'pain' for society and business. The stakeholders consulted were divided on which of the two metrics to use. For simplicity, we have chosen to present damages in absolute terms, but we also provide information on the economic wealth generated within each scenario (Table 1.3). In this way transparency of the findings is ensured. In Chapter 5 we present a series of maps of future risk, expressed in absolute terms. However, as an exception, we have also included one set of maps which have been normalised by national wealth.

Economic valuation of risks can, to some extent, be thought of as a proxy for the risks to life from flooding, as both economic loss and risk to life are related to the type and location of homes and industries in floodplains. Nonetheless, the health and social impacts of flooding require special attention, especially as the less well-off are among the most vulnerable, so may not be well represented in economic statistics (though use of nationally averaged economic statistics does mitigate against this bias). We have specifically addressed the social impacts of flooding in our assessment of the drivers of flood risk in Chapter 2, and in the use of Social Flood Vulnerability Indices (Tapsell *et al.* 2002) in our quantified assessment of flood risk (Chapter 4).

Finally, we have considered the evaluation of the impact of flooding on the environment. This requires special treatment since it can give rise to both beneficial and harmful effects. The potential for significant beneficial impacts on the environment of increased flood frequency (and consequent changes in agricultural practices) means that it is more appropriate to use a less risk-based and more holistic analysis than when assessing the economic and health/social impacts. Therefore, the environmental impacts of flooding were treated separately (see Chapter 7). On the other hand, the influence of future changes in the environment, due, for example, to changed agricultural practices, on flood risk, are amenable to the risk assessment methodology described above, and so were included in the study.

1.7 Science and technology

Science and technology, including engineering technologies, will be as vital in the management of flood risk in the future, as they have been in the past. Just as windmills were vital in draining flooded agricultural land in the 1700s to provide food for a growing population, so weather radars and complex computer simulations help to predict floods today. Science will similarly help us to manage flood risks in the future, although we cannot now easily predict precisely how.

In general, however, we pursue and deploy science and technology to advance our economies and societies. We can summarise the output (O) of an economy as being:

$$O = NE * T * H * X$$

Where

NE is the natural endowment

T is technology

H is human inputs of labour and capital

X is some other factor which may include institutional form and other factors such as social capital and social adaptability

Hence the role of $T * X$ is to maximise the ratio of O to $NE * H$, given that NE is permanently fixed and H is relatively fixed in the short term.

Science and technology act in several different ways in relation to flood risks:

1. By affecting **receptors**, so as to increase flood losses: technological advance seems typically to increase our assets' susceptibility to flood damage (e.g. home cinemas and advanced railway signals are more susceptible to flood damage than their simpler predecessors). This is dealt with mainly in Volume I.
2. By affecting **pathways**, so as to affect flood runoff (e.g. modern large-scale tractors and other farm equipment influencing rural land management). This is also dealt with mainly in Volume I.
3. By affecting **responses**, so as to improve our capacity to manage floods successfully, thereby increasing the overall ratio of O to $NE * H$. Indeed, our objective in flood management is to increase this ratio rather than to minimise flood losses *per se*. This is dealt with mainly in Volume II.
4. By reducing **uncertainty**. Science gives us new insights into the world in which we live, enabling us to have:

- A better understanding of natural processes, such as precipitation.
- More accurate predictions of the incidence, location and consequences of flooding (which this Foresight project shows are fraught with uncertainties).

- Better designs and technologies for flood-mitigation options.
- A better understanding of the complexities facing policy-makers and better balances between competing stakeholder interests.

Thus, better science should lead to better decisions, and more sustainable outcomes, although this is not axiomatic.

More generally science and technology is also an enabler that helps to generate wealth in the country and thereby contributes to enhancing the quality of life in the UK. Just as science can lead to vaccines to protect against disease or to progressively cheaper computers, so it can help to provide the resources for protecting vulnerable communities from flooding and from the damage, distress and loss of life that can result.

These important roles for science and technology and the results that they can bring do not come about automatically, but require a number of ingredients:

- A consistent and coherent science policy.
- Implementation over many decades.
- A skilled science community supported by the resources that are necessary for their work.
- A receptive public, professional and political audience.

In this project science and technology is seen as an important driver of flood risk, for the reasons outlined above. However, it is not treated in the same way as other drivers. This is because:

- It works indirectly in affecting other drivers (e.g. by affecting the infrastructure of our cities or the ways that we manage our land).
- Science and technology is both a driver affecting flood risk (Volume I) and can be a response to mitigate that risk (Volume II).

The first point leads us not to rank this driver against others, in Chapter 2 here and thereafter, because that would result in double-counting. The second means that the true importance of science and technology and its role in flood and coastal defence can only be appreciated with reference to both Volumes.