Foresight
Future Flooding

Executive Summary

This report is intended for:

Policy-makers in central and regional Government and the private sector. It will also be of interest to a wide range of professionals, whose work is affected by flooding and coastal erosion, including planners, environmentalists, those in business, social scientists, researchers and flood managers.

This report has been produced by the Flood and Coastal Defence project of the Foresight programme. Foresight is run by the Office of Science and Technology under the direction of the Chief Scientific Adviser to HM Government. Foresight creates challenging visions of the future to ensure effective strategies now.

Foreword

Flooding affects us all. Over £200 billion worth of assets are at risk around British rivers and coasts and in towns and cities, and we are all vulnerable to the disruption of transport and power when a major flood occurs. Fortunately, Government already does much to protect society and the environment. However, the risks are set to increase over the next hundred years due to changes in the climate and in society.

I therefore commissioned this scientific study to answer the following questions:

How might the risks of flooding and coastal erosion change in the UK over the next 100 years?

What are the best options for Government and the private sector for responding to the future challenges?

The work has been performed by a team of 60 leading experts, and constitutes the most wide-ranging analysis of the problem of increasing flood risk that has ever been made in the UK and possibly internationally.

There are two key messages. Firstly, continuing with existing policies is not an option – in virtually every scenario considered, the risks grow to unacceptable levels. Secondly, the risks need to be tackled across a broad front. Reductions in global emissions would reduce the risks substantially. However, this is unlikely to be sufficient in itself. Hard choices need to be taken – we must either invest more in sustainable approaches to flood and coastal management or learn to live with increased flooding.

The work presented here is an independent scientific look at the future. The findings do not constitute Government policy. Nevertheless, I would like to acknowledge the considerable advice and assistance provided by Defra and the many other government departments and private sector stakeholders. I am particularly pleased that many of these are already taking this work further.

Sir David King KB ScD FRS
Chief Scientific Adviser to HM Government
and Head of the Office of Science and Technology

Preface

I am delighted to receive this report from Sir David King. It represents the use of excellent science to inform better decisions on our longer-term strategy on the management of flood risks.

Flood defence is not just a matter of investing the right amount of money to reduce the costs of flooding, it is also about protecting people and the environment. This is why it is an issue which is close to my heart. It is important that as a nation we get it right.

We cannot, of course, eliminate the risk of flooding. But we can seek to manage the risks. I am pleased with the considerable successes that we have had recently in managing the risk of flooding in the UK. However, I recognise that investment decisions made now will leave a legacy for the future. That is why this project is of such value. It provides a better understanding of the risks that we could face and the uncertainty in the future that must be managed. Its value for policy across Government is considerable.

Sir David's report has highlighted once again the wide range of players who will be affected by changes in the amount of flooding and who will play an important part in ensuring that we have an effective response to those changes. This project has brought all of those players together and has helped to build a shared understanding of the challenges that we face.

I am keen to capitalise on the valuable resource the project provides, both in terms of the community and the analysis. I have therefore worked closely with those key players to prepare an action plan. This plan sets out how we will use this report as a resource to challenge and inform our investment strategies.

An important area it will feed into, is my Department's 20-year strategy. Through this, and a number of other channels across Government, the project will leave a lasting impression on the approach we take to flood management in the UK. It provides a critical piece of new analysis that will help us take better decisions on our long-term strategy on flood defence.

Elliot Morley MP
Minister for Environment and Agri-Environment
Defra

Future Flooding Executive Summary

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Chapter 1

Introduction

The aim of the project

To use the best available science to provide a challenging vision for flood and coastal defence in the UK between 2030 and 2100 and so inform long-term policy.

An independent look:

while the Office of Science and Technology commissioned the work, the findings are independent of Government and do not constitute Government policy.

A broad scope:

the work covers all of the UK and looks at flooding from rivers and the sea, as well as internal flooding in towns and cities. It also considers the risks of coastal erosion.

Sustainability analysis at the heart:

we have looked at economic, social and environmental consequences.

Why the study was needed

Decisions taken today will have a profound impact on the size of flooding risks that future generations will need to manage. They will also strongly influence the options available for managing those risks.

Large engineering works have long gestation times and long lifetimes. For example, studies are starting now for replacing or upgrading the Thames Barrier around 2030 – and the new defences will be expected to work for many decades after that. Within cities, we rely on Victorian sewers to drain stormwater. By the end of the century some of those sewers will be 250 years old.

There is considerable inertia in the built environment. If we want to alter land use in flood plains and alongside rivers within cities, it could take decades for changes in planning policies to take effect.

Reducing global greenhouse-gas emissions could play an important role in mitigating flood risk in the second half of the century. However, the time delay inherent in the atmosphere and oceans means that action needs to be taken now to achieve that.

Using future scenarios to develop robust policies

The future is very uncertain and cannot be predicted. It is therefore important to develop policies that can cope with a range of different outcomes – and which can adapt flexibly as the situation evolves. The greater the uncertainty, the greater the need for flexibility.

We have analysed future risks of flooding and coastal erosion for four different future scenarios. These scenarios are the Foresight Futures – they embody different approaches to governance (centralised versus localised) and different values held by society (consumerist versus community).

We also associated each socioeconomic future with a different climate-change scenario: a high-growth socioeconomic scenario (termed ‘World Markets’) is matched with high greenhouse emissions and so on (see Figure 1.1). Many other combinations are possible, but the four we have chosen are sufficient to investigate a wide range of possible futures.

Risk is taken to mean:

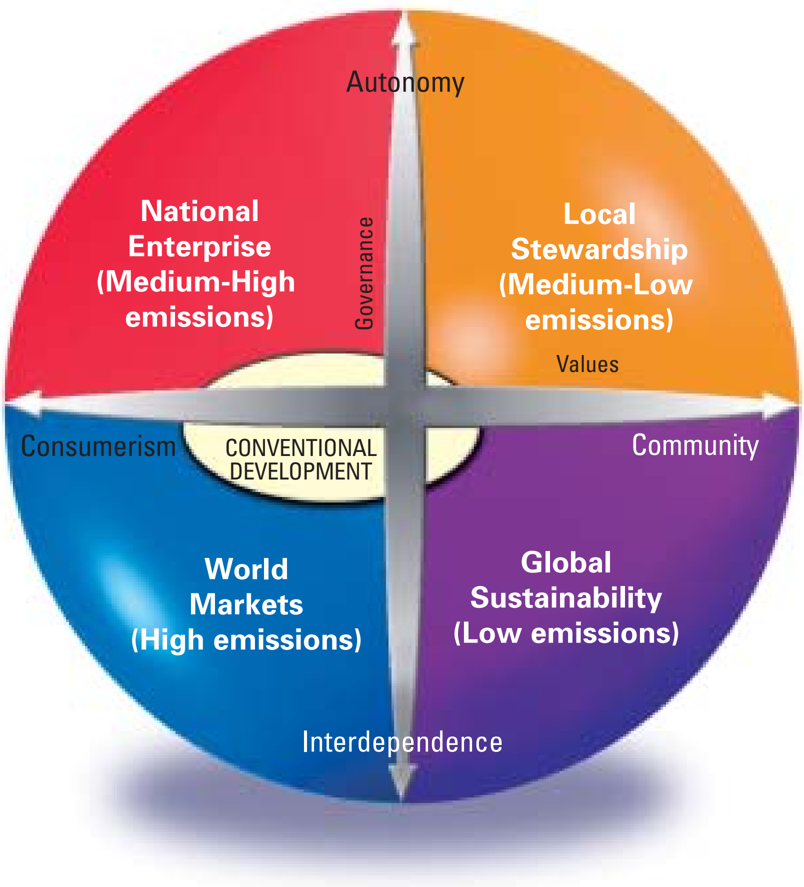
probability x consequences
> ***– where consequences relate to people, and the natural and built environments***

However, an additional factor – public outrage – will affect the levels of risk that are acceptable to future societies.

The four scenarios are set out in the four quadrants of Figure 1.1 and described in the Appendix.

Figure 1.1 **The four scenarios used**

The vertical axis shows the system of governance, ranging from autonomy, where power remains at the local and national level, to interdependence, where power increasingly moves to international institutions. The horizontal axis shows social values, ranging from consumerist to community-oriented.



Chapter 2

Risks of flooding and coastal erosion – today and in the future

This chapter examines how the extent and nature of flooding and coastal erosion might grow over the next 100 years under the 'baseline assumption' that we do not change existing policies or expenditure on flood risk management. This enables us to see where policy change could usefully be considered.

The baseline assumption underpinning Chapter 2

'Current levels of expenditure and approaches to flood management remain unchanged.'

Q1 What are today's risks of flooding and coastal erosion and how much is spent on reducing these risks?

Nearly 2 million properties in floodplains along rivers, estuaries and coasts in the UK are potentially at risk of river or coastal flooding. Eighty thousand properties are at risk in towns and cities from flooding caused by heavy downpours that overwhelm urban drains – so-called 'intra-urban' flooding. In England and Wales alone, over 4 million people and properties valued at over £200 billion are at risk.

Table 2.1 **Summary of present-day flood risks and flood-management costs**

	Properties at risk	Average annual damage (£ million)	Flood management costs 2003-04 (£ million)
River and coastal flooding			
England and Wales	1,740,000	1,040	439
Scotland	180,000	32 (fluvial only)	14
Northern Ireland	45,000	16 (fluvial only)	11
Intra-urban flooding			
All UK	80,000	270	320
Total	**2,045,000**	**1,400**	**800**

(Totals are rounded)

Flooding, and managing it, cost the UK around £2.2 billion each year: we currently spend around £800 million per annum on flood and coastal defences; and, even with the present flood defences, we experience an average of £1,400 million of damage (see Table 2.1). While the level of spending is fairly steady, damage due to flooding is intermittent and can be huge when a major flood occurs.

Flood defences protect not only people and private properties, but also vital amenities and public assets, including hospitals, the emergency services, schools, municipal buildings and the transport infrastructure. Disruption of these by flooding can have major knock-on effects for business and society.

Q2 How might economic risks grow over the next 100 years?

If flood-management policies and expenditure are unchanged, annual losses would increase under every scenario by the 2080s. However, the amount of that increase varies, from less than £1 billion under the Local Stewardship scenario with Medium-Low emissions of greenhouse-gasses, to around £27 billion in the 2080s under World Markets and High emissions.

Chart 2.1 estimates the average annual damage in the 2080s. The differences are due to varying amounts of climate change, different increases in the value of assets at risk and new development in flood-prone areas. The two consumerist scenarios contrast with the two community-oriented scenarios, which experience much more modest increases. These figures underestimate the total cost of flooding – they exclude consequential losses, for example, due to disruption of transport.

When the damages are expressed as a proportion of Gross Domestic Product (GDP), the variation between scenarios is much less. Indeed, for the two community-orientated scenarios, the ratio is better than today (Chart 2.2). In the case of World Markets/High emissions, the high growth in the economy offsets the large increases in flood risk. However the National Enterprise/Medium-High emissions scenario fares the worst because it embodies quite high levels of climate change, but relatively poor growth.

Chart 2.1 **Average annual damage for all of the UK (£ billion) assuming flood-management approach and expenditure remain unchanged – present day and 2080s**

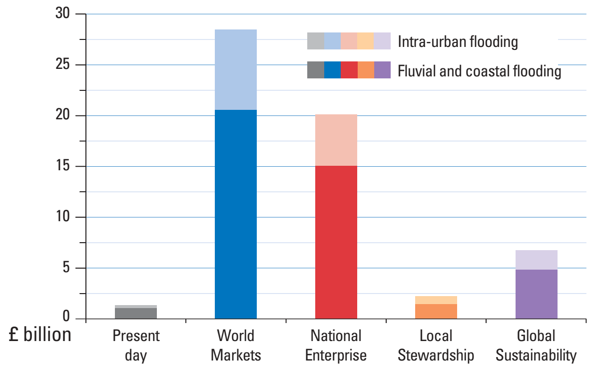
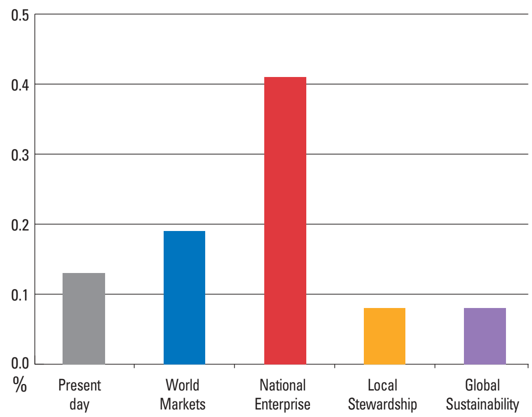


Chart 2.2 **Average annual damage from flooding across the UK expressed as a percentage of GDP – present day and the 2080s**

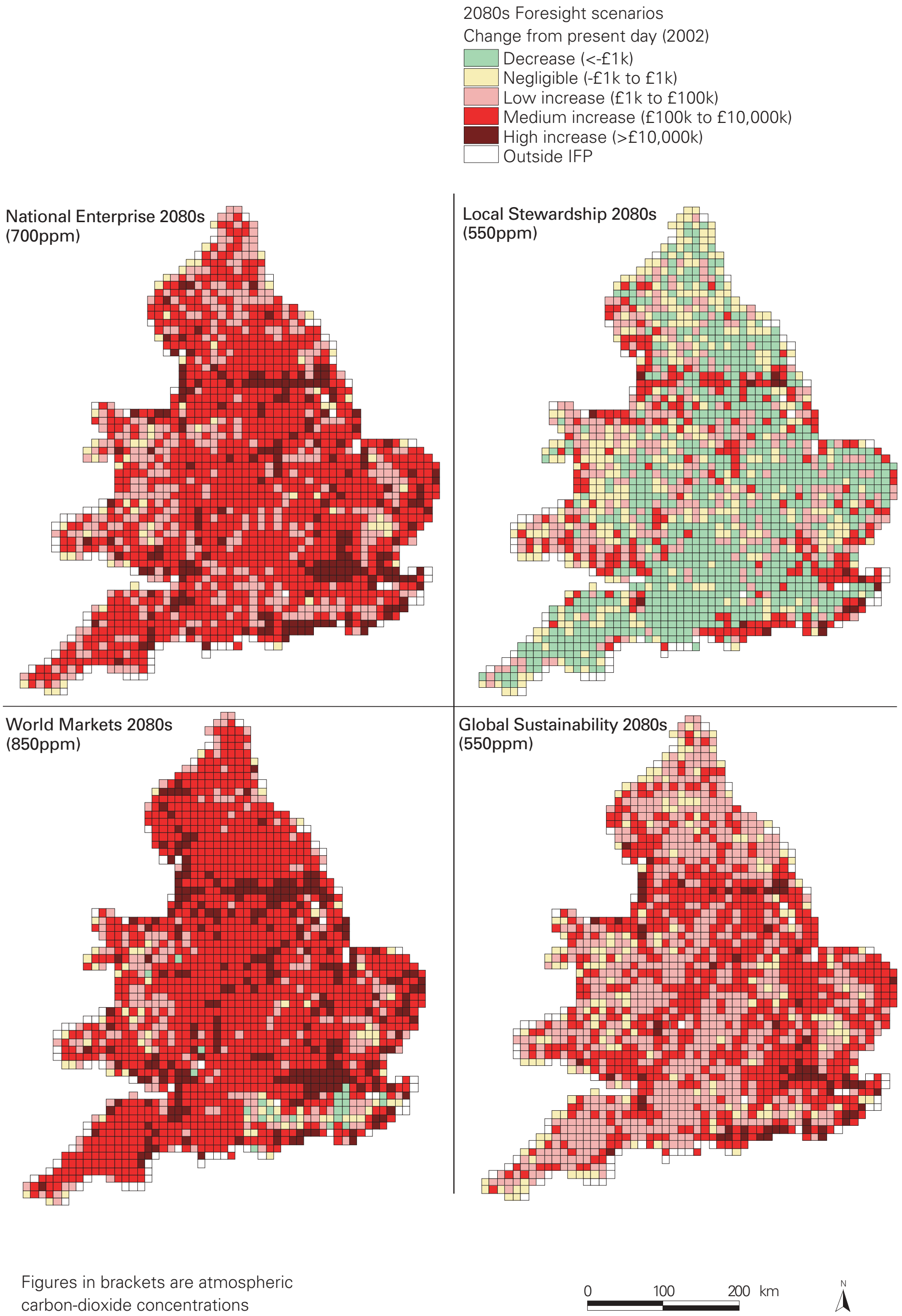


Changes in the distribution of damages across the country varies widely for the four future scenarios in the 2080s (see Figure 2.1). However, some parts of the country consistently have the worst increases – the Lancashire/Humber corridor, parts of the coast (particularly in the south-east) and major estuaries. (Note: our analysis here, relates only to England and Wales due to the limited availability of data for Scotland and Northern Ireland.)

The picture for agricultural risk also varies, reflecting the nature of agriculture in the UK under four very different policy frameworks. Under the globalised scenarios of World Markets and Global Sustainability, much lower-grade land might go out of production: agricultural damages might decrease over much of England and Wales. By contrast, under the localised scenarios of National Enterprise and Local Stewardship, damages increase because agriculture has greater value and is more widespread.

> ‘The estimation of future flood risks is difficult due to future uncertainties. However, all scenarios point to substantial increases.’

Figure 2.1 **The distribution of average annual damage from flooding across England and Wales in the 2080s. The maps represent changes in risk by the 2080s for the four future scenarios. Darker shades of red signify progressively greater increases in damage. Green signifies a reduction.**



Figures in brackets are atmospheric carbon-dioxide concentrations

Q3 What are the additional risks in the urban environment?

Besides flooding from rivers and coasts, towns and cities will be subject to localised flooding caused by the sewer and drainage systems being overwhelmed by sudden localised downpours. The potential damages could be huge, but much more work needs to be done to quantify the potential problem.

Chart 2.3 **Number of properties in the UK at high risk from intra-urban flooding – today and in the four future scenarios in the 2080s**

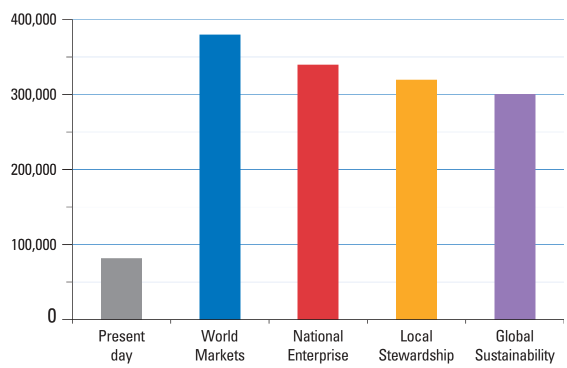
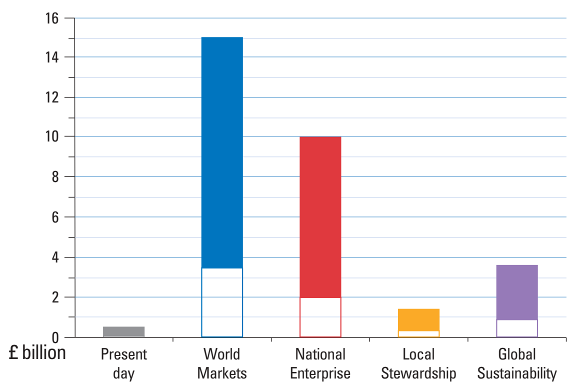


Chart 2.4 **Average annual damage from intra-urban flooding for the UK in the 2080s (£ billion) the coloured bars show the range of possible values for each scenario**



The numbers of properties at high risk of localised flooding could typically increase four-fold under the four future scenarios (see Chart 2.3 – high risk means a 10% chance of flooding in any year).

Chart 2.4 details possible annual damages. These are plotted as bands to show the uncertainty in the results. The key message is that the increases could be huge, but there is considerable uncertainty – much more research is needed.

Two particular factors make localised flooding in towns different to flooding from rivers and coasts.

- For relatively small degrees of climate change, the urban drainage system may cope reasonably well, as the excess capacity in the sewer and drainage pipes absorbs the increases in water flows. But if the climate change increases further, the system would reach its capacity more frequently, and the incidence of flooding would rapidly escalate.

- Urban flood waters are invariably mixed with sewage, so future increases in urban flooding would be compounded by the additional risks to health, and higher costs of repair to properties.

One of the key findings is the inadequacy of present tools in modelling and predicting intra-urban flooding. This makes these results more uncertain than those of river and coastal flooding – but the message of increasing risk is still clear.

Q4 What will be the risks from coastal erosion?

Coastal erosion will increase substantially under the baseline assumption – i.e. spending on coastal defence continues at present levels. The annual average damage is set to increase by 3 - 9 times by the 2080s, although the worst case (£126 million per year) is still much less than current flood losses (£1 billion per year).

Present levels of expenditure on coastal defence will not keep pace with coastal erosion in the coming decades and approximately one-third of existing coastal defences could be destroyed. Increased sea level and more intense and frequent storms due to climate change will increase the damage to defences.

Erosion rates increase in every future scenario (see Chart 2.5 – the bands show the uncertainty in the results). Chart 2.6 details the average annual damage. In the worst case these could increase nine-fold to £126 million per year. While this is small when compared with present-day flood risk (£1 billion per year), coastal erosion will often occur in areas vulnerable to flooding and will compound flood risks.

Chart 2.5 **Average coastal erosion over the next 100 years (metres) – the coloured bars show the range of possible values for each scenario**

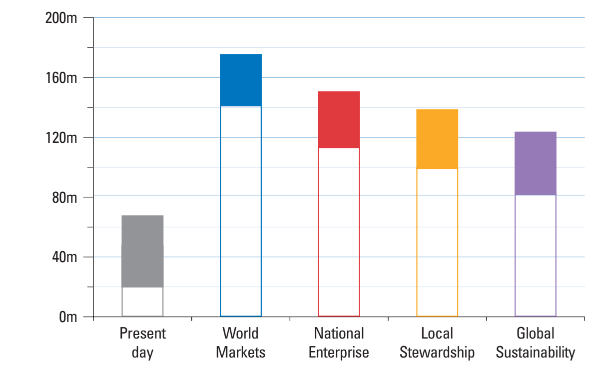


Chart 2.6 **Average annual damage due to coastal erosion for the 2080s for England and Wales (£ million)**

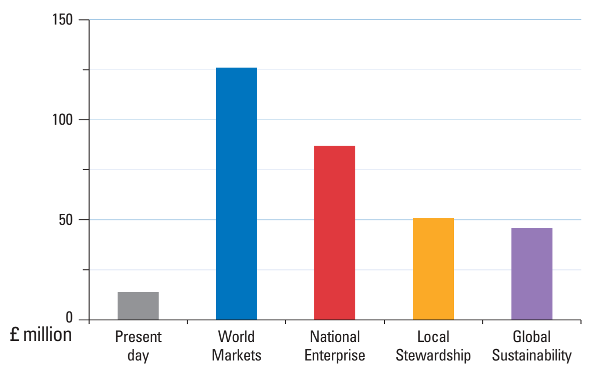
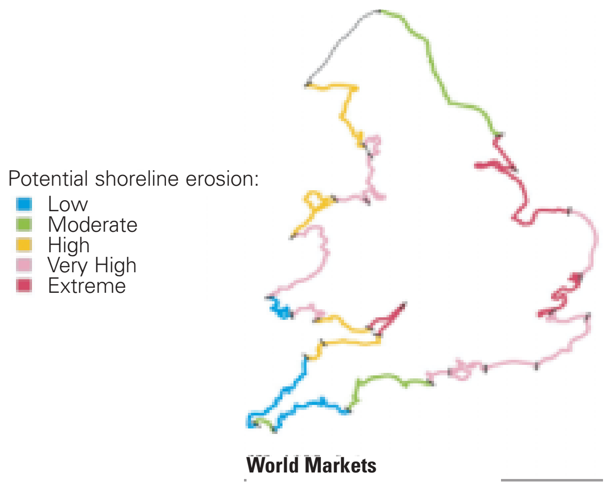


Figure 2.2 **Coastal erosion under the World Markets/ High emissions scenario in the 2080s.**



Areas under greatest threat from erosion will be along major estuaries and the east coast. Figure 2.2 details possible future erosion rates for the World Markets scenario (the pattern is broadly similar in the other scenarios). However, local erosion rates could differ widely from these averages.

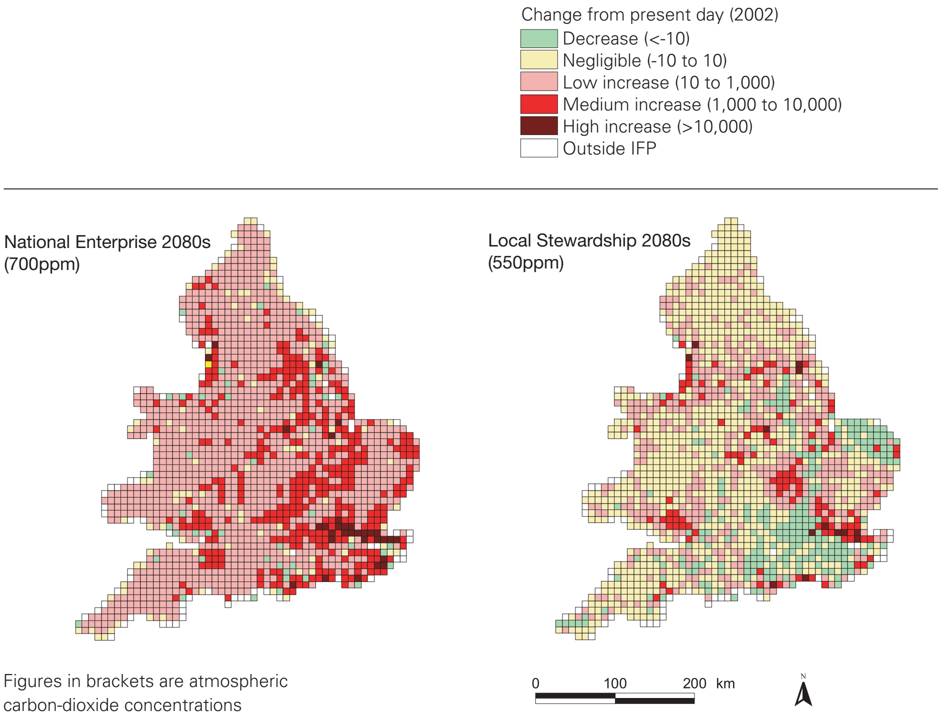
A considerable amount of important infrastructure is on the coastal strip. Some structures, such as oil refineries, could be relocated at the end of their design life. However, other assets, such as coastal towns, will be difficult to relocate. In Wales and other parts of the UK, erosion would threaten beaches and therefore tourism.

Q5 What will the risks be to people?

The number of people at high risk from river and coastal flooding could increase from 1.6 million today, to between 2.3 and 3.6 million by the 2080s. The increase for intra-urban flooding, caused by short-duration events, could increase from 200,000 today to between 700,000 and 900,000 (see Charts 2.7 and 2.8).

The numbers of people at risk will be strongly affected by future socioeconomic policies. Figure 2.3 shows how the numbers of people at high risk of river and coastal flooding could change by the 2080s for the scenarios National Enterprise/Medium-High emissions and Local Stewardship/Medium-Low emissions. While the former scenario embodies greater climate change, the considerable difference between the two is dominated by factors such as land-use policies and the rate of economic development. Indeed, under the Local Stewardship scenario, many areas of England and Wales have fewer people at risk then at present (the green squares).

Figure 2.3 **Change in number of people at high risk in 2080s – National Enterprise and Local Stewardship scenarios. Darker shades of red signify progressively greater numbers of people at high risk. Green signifies a reduction in risk.**



Figures in brackets are atmospheric carbon-dioxide concentrations

The human cost of flooding cannot be measured by statistics alone:

- There will be substantial health implications, particularly when the floodwaters carry pollutants or are mixed with foul waters from drains and agricultural land. The floodwaters could also cause indirect health hazards by making sewage treatment works inoperable for extended periods and spilling their contents over the landscape – as happened in the recent central European floods.

Chart 2.7 **Number of people at high risk now and in the 2080s – river and coastal flooding ('high' means a chance of flooding of greater than 1:75 in a given year)**

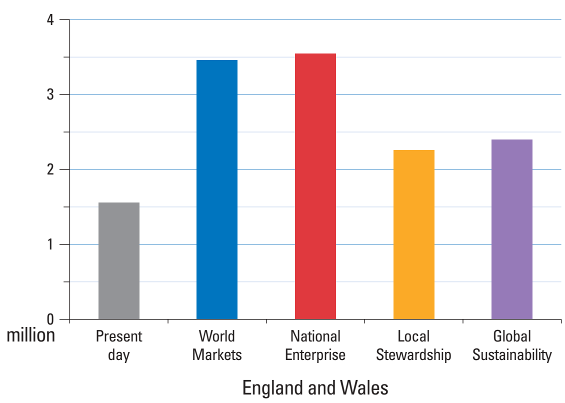
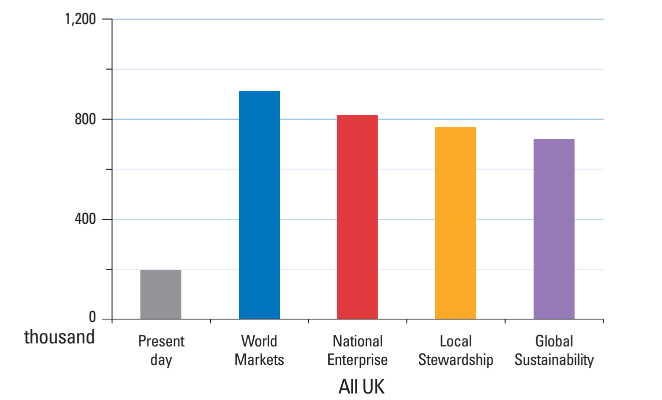


Chart 2.8 **Number of people at high risk now and in the 2080s – intra-urban flooding ('high' means a chance of flooding of greater than 1:10 in a given year)**



- There will be mental-health consequences. Besides the considerable stress of extensive damage, the threat of repeat flooding, coupled with the possible withdrawal of insurance cover can make properties unsaleable, and cause long-term depression in the victims.
- The socially disadvantaged will be hardest hit. The poor are less able to afford flooding insurance and less able to pay for expensive repairs. People who are ill or who have disabilities will be more vulnerable to the immediate hazard of a flood and to health risks due to polluted floodwaters.

Q6 What will be the implications for the environment?

Increased flooding could bring both opportunities and threats to the environment. Saltmarshes could benefit from abandonment of uneconomic coastal farmland under some scenarios, but habitats such as coastal grazing marsh are threatened under every scenario.

Periodic flooding is essential for the health of many of our fluvial and coastal ecosystems. However, extensive land drainage, river channelisation and an increase in the control of flooding has contributed to a significant loss of wetland habitats and biodiversity over the last century in the UK.

In the future, the drivers of changing river flows are likely to increase both water and sediment discharge. Hence there will be a tendency towards a widening and deepening of river channels.

On the coast, ecosystem change will be driven by both sea-level rise and flood-management policy. Coastal grazing marsh appears to be the most threatened coastal habitat under all four Foresight Futures, as intertidal losses of saltmarsh and mudflat are likely to be offset by coastal realignment or abandonment of grazing marsh (planned or unplanned).

Figure 2.4 **Saltmarsh (A) and coastal grazing marsh (B) in East Anglia**

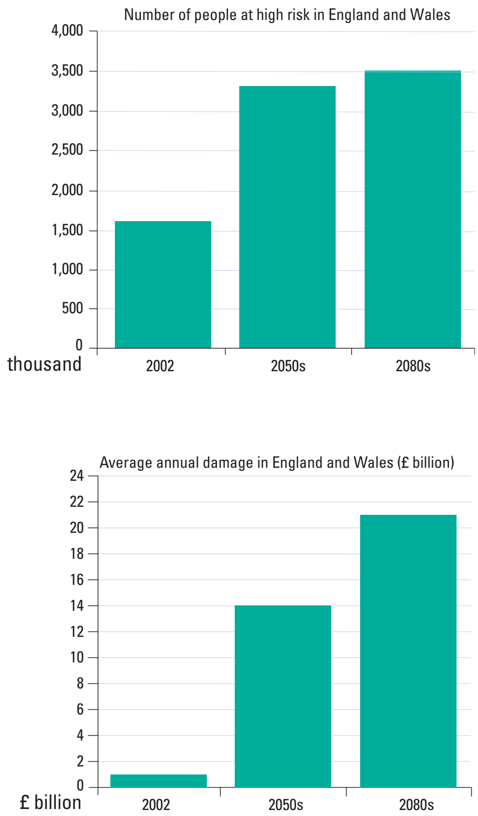
Saltmarsh and other intertidal habitats could benefit from increased flood frequencies. However, coastal grazing marsh is threatened under all scenarios.

Q7 How quickly might the risks grow?

The rate of increase in flood risk depends on the scenario. We looked at the World Markets/High emissions scenario in the 2050s and 2080s – the increase in economic damages increased approximately linearly. However, the increases in the number of people at high risk rose very rapidly – 90% of the increases had occurred by the 2050s.

Chart 2.9 illustrates the changes in the total risks for the World Markets/High emissions scenario. The average annual damage and number of people at high risk from river and coastal flooding are plotted. This shows that most of the increases in people at risk have accumulated by the 2050s, whereas economic risks rise more slowly.

Chart 2.9 **Increase in risks for World Markets in the 2050s and 2080s (catchment and coastal case)**



The rate of increase in flood risks will vary between scenarios and will be influenced by three factors:

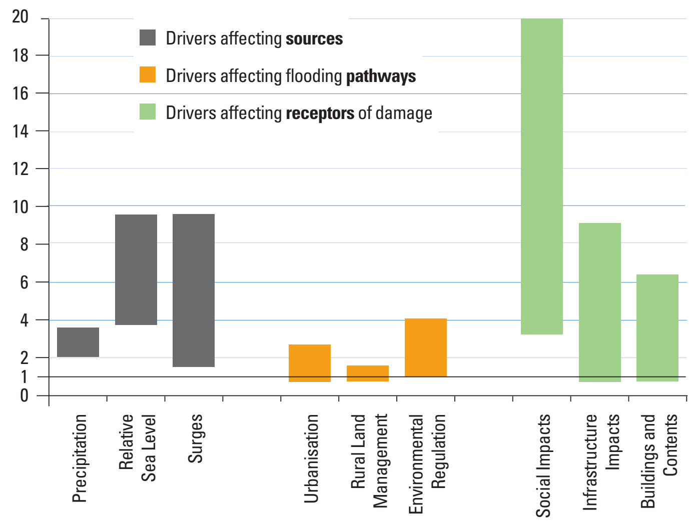
- Climate change – the particular climate-change scenario we associated with World Markets has a rapid rise in global emissions of greenhouse-gases from now until 2080 and then flattens out. Other emissions scenarios start with slower rates of increase (see Appendix A).
- The rate at which the value of the properties and infrastructure at risk increase.
- The rate at which building takes place in flood-risk areas.

Q8 What will be the main drivers of future risk?

Many powerful drivers will influence future flood risk. Climate change, socioeconomic factors that influence the vulnerability of people and value of assets at risk, and governance issues such as stakeholder behaviour and environmental regulation, all feature prominently.

We evaluated the influence of 19 drivers on future flood risk for each of the four future scenarios (see Chart 2.10).

Chart 2.10 **An illustration of how some of the key drivers examined could multiply present day national flood risk in the 2080s – the bars show a range of possible values depending on scenario**

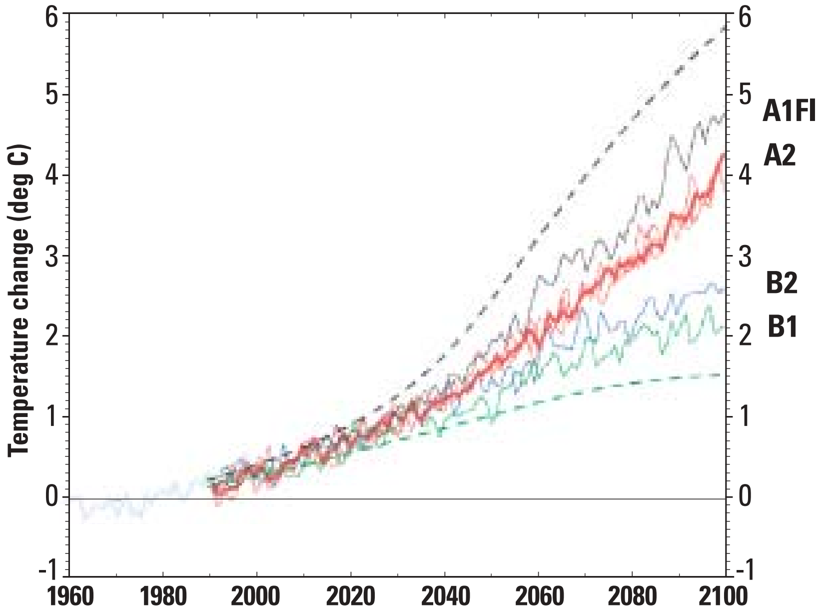


- **Climate change** – has a high impact in every scenario. Risks at the coast will be particularly affected: relative sea-level rise could increase the risk of coastal flooding by 4 to 10 times. Precipitation will increase risks across the country by 2 to 4 times, although specific locations could experience changes well outside of this range.
- **Urbanisation** – particularly in flood-prone areas, could increase rainwater runoff, increasing flooding risk by up to 3 times. At the same time, new developments and weak planning controls on the types, densities and numbers of new buildings could also increase risk. There is a clear message here regarding the importance of urban development to future flood risk.
- **Environmental regulations** – could be risk-neutral or could affect flood pathways by constraining maintenance and flood-risk management along rivers, estuaries and coasts, thereby raising risk. This argues for an integrated approach to decisions on flood management and environmental regulation in order to achieve multiple benefits for people and nature.

- **Rural land management** – a recent major study showed that there is substantial evidence that current land-management practices have led to increased surface runoff at the local scale. However, there is a general absence or uncertainty of evidence of the impacts at the catchment scale. There is also a lack of knowledge of how small-scale impacts combine at larger scales. Further research has been recommended to explore the possible impacts of land-management practices at both local and catchment scales.
- **Increasing national wealth** – will increase the value of the buildings and assets at risk and is therefore a strong driver of economic impacts. However, increases in flood damage as a proportion of national wealth will be much smaller and may even reduce in certain scenarios.
- **Social impacts** – these are difficult to quantify, but the analysis showed a large increase in social risks in all scenarios, by 3 to 20 times. Unless these risks are managed, significant sections of the population could be blighted.

Many of the drivers that could have the most impact are also the most uncertain. Some of this uncertainty relates to scientific understanding – for example, uncertainties in how to model the climate. However, other sources of uncertainty are inescapable – such as the extent to which the international community will succeed in reducing greenhouse-gas emissions (see Figure 2.5). It is therefore important to develop policies that can cope with a wide range of possible futures, and which can respond flexibly to an evolving world.

Figure 2.5 **High uncertainty in climate-change predictions: 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.**



Chapter 3

Options for responding to future challenges

This chapter looks at options for responding to the future risks identified in Chapter 2.

Around 120 responses have been considered – these have been analysed in groups and together as part of integrated approaches.

First, we look at which responses might be best at reducing future risks, and by how much we could feasibly reduce those risks. We then consider the wider implications of sustainability and governance. Local flooding in towns and cities is considered as a special case at the end.

Q9 Which might be the best responses for reducing future catchment-scale flood risks?

A wide range of responses can make substantial reductions in future risk. Their effectiveness depends very much on the scenario. However, no single response can adequately reduce the considerable risks that were identified in Chapter 2. (Note: risk reductions through mitigating climate change are considered separately in question 11).

We considered around 80 different catchment-scale responses in five broad themes (see Table 3.1).

Table 3.1 **Catchment-scale responses**

Theme	Examples
Managing the Rural Landscape	Catchment-Wide Storage
Managing the Urban Fabric	Urban Storage
Managing Flood Events	Forecasting and Warning Individual Damage Avoidance Actions
Managing Flood Losses	Land-Use Management Floodproofing
River and Coastal Engineering	Increasing River Conveyance River Defences Coastal Defences Coastal Defence Realignment and Abandonment

Chart 3.1 **The factors by which key responses could multiply future flood risk at catchment and coastal scales**

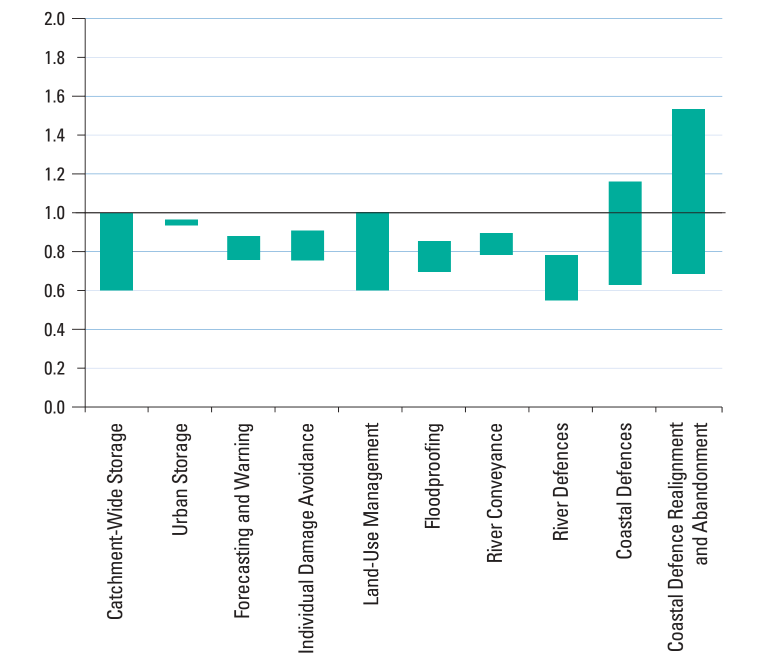


Chart 3.1 details the range of possible reductions in flood risk for each of the responses in Table 3.1. The range of the bars indicates the range of reductions which might be possible between the four future scenarios. It is seen that many different types of response can contribute to reducing future risks.

However, while certain responses can reduce risk by up to 45%, all fall well short of reducing the considerable risks (up to 20 times today's levels) identified in Chapter 2. In the future, as now, we will need an integrated approach whereby policies are joined up and many different responses are deployed in an integrated manner. This is considered in the next question.

Sustainability of the responses:

Ideally, we want to identify responses which are effective in reducing risk, and which are also sustainable. We therefore assessed the responses against economic, social and environmental sustainability criteria.

We found that none scored highly in effectiveness and sustainability across all four scenarios. However, several performed well across three of the four, and are therefore reasonably robust to socioeconomic and climatic change. These include:

- Catchment-Wide Storage.
- Land-Use Planning.
- Realigning Coastal Defences.

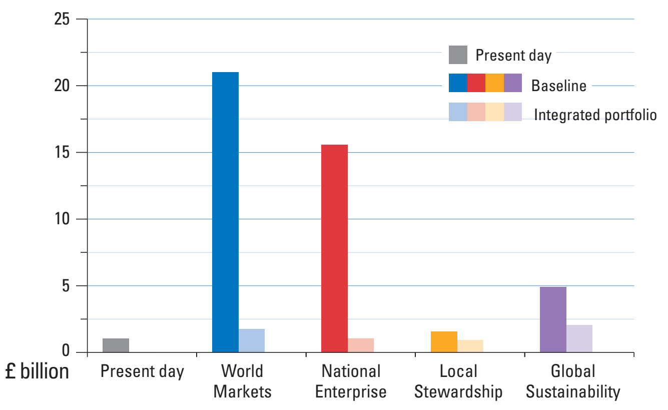
All of these can produce environmental benefits, reduce flood risk and be made sustainable with careful implementation.

Social justice was a hurdle to sustainability in a number of responses. The key message is that, it is how the responses are implemented that is the critical factor – more than the responses themselves.

Q10 If responses are combined, by how much would risks fall?

An integrated portfolio of responses could reduce the risks of river and coastal flooding from the worst scenario of £20 billion damage per year, down to around £2 billion in the 2080s. However, this would still be double present-day damage.

Chart 3.2 **Average annual flood damage in 2080s for the four future scenarios – baseline damages (assuming no change in policies) compared with damages following implementation of the integrated portfolios of responses**



The project constructed an integrated portfolio of responses for each of the four future scenarios and assessed its ability to reduce flood risk in the 2080s. Each portfolio drew on the same menu of responses. However, the extent to which each response was used depended on the scenario – for example, responses requiring strong regulation tended not to be used in scenarios embodying non-interventionist governance.

A different target level for protection from flooding was assigned to each scenario. To be consistent with the wealth and public expectations of each: for the scenarios World Markets and National Enterprise the target for protection is double present-day; Global Sustainability used the same level as today; and Local Stewardship embodied a 25% reduction in protection.

Figure 3.1 shows how the geographical spread of risks is reduced for the National Enterprise scenario when compared with the baseline case, which assumes no change in flood-management policies. Areas of high risk around the coast and major estuaries have been largely eliminated in the right-hand map.

Chart 3.3 **The number of people at 'high' risk in the 2080s for the four future scenarios – baseline case (assuming no change of policies) compared with implementation of the integrated portfolios of responses**

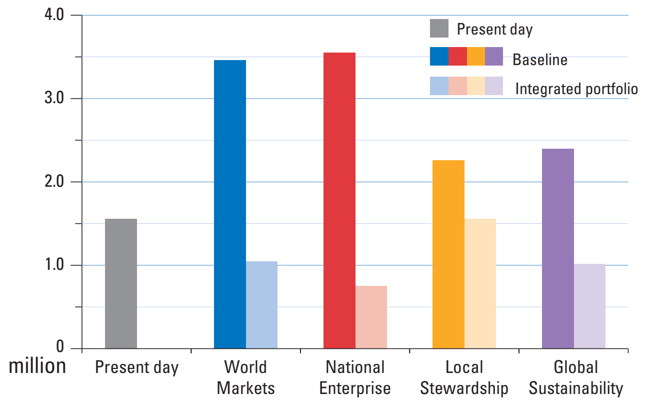
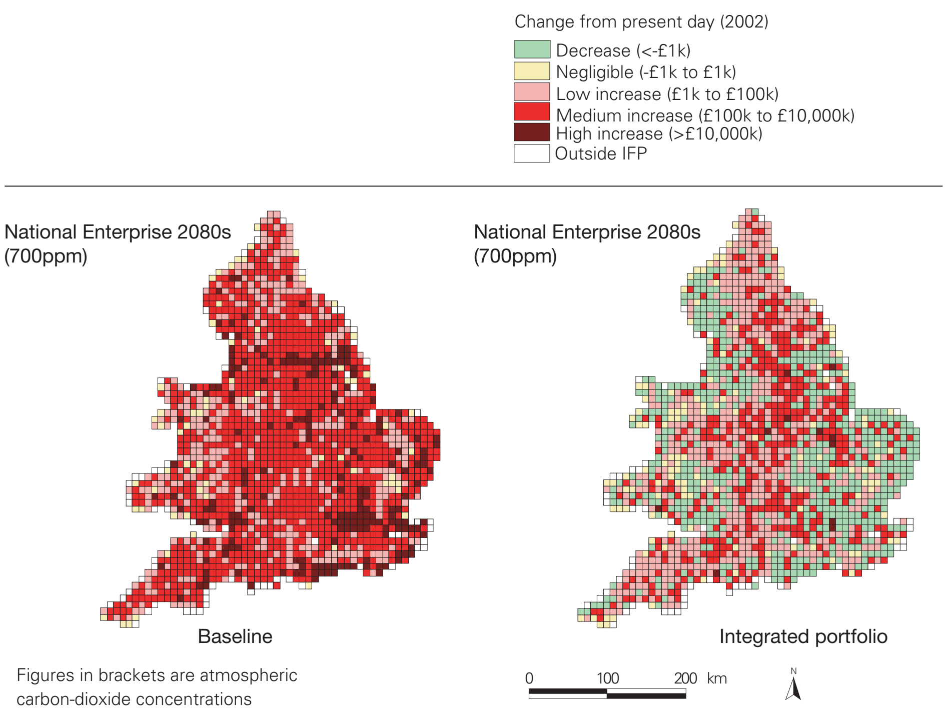


Figure 3.1 **Change in average annual damage (commercial & residential property) when an integrated portfolio of responses is implemented (right), compared with the baseline case (left).**



Figures in brackets are atmospheric carbon-dioxide concentrations

Q11 To what extent would reducing greenhouse emissions help to reduce risk?

We looked at the high-growth World Markets scenario in two cases – coupled with High and Low global emissions of carbon dioxide. In the absence of other responses, the risks of catchment and coastal flooding fell from around £21 billion per year to around £15 billion per year in the 2080s. These figures do not include risk reductions for intra-urban flooding, which would be additional.

We saw in Chapter 2 that a future embodying World Markets socioeconomics and High global emissions results in high growth and prosperity, but also very high risks from flooding and coastal erosion. However, combining the high growth of World Markets with Low global emissions substantially reduced the risks. When implementing measures to reduce global greenhouse-gas emissions, together with the integrated portfolio of responses detailed above, it would therefore be much easier to reduce risk levels to around (or below) present-day values.

In the case of intra-urban flooding, mitigating climate change could make the difference between the existing system of drains and sewers coping, or reaching the limit of their capacity.

Reductions in flood-risk resulting from climate-change mitigation would mostly accrue in the second half of the century – action to reduce emissions would have limited affect before then because of the long time lag in the atmospheric system. Equally, this time lag implies the need to take action now to reduce emissions, if we want to affect risks in the 2050s and beyond.

Q12 What are the economic, social and environmental implications of flood management using a portfolio of responses?

To implement the portfolios of responses would require between £22 billion and £75 billion of new engineering by the 2080s, depending on scenario. Ensuring that flood management does not have social or environmental costs would be more difficult in certain scenarios. However, sensitive implementation of the responses has the potential to reduce these concerns.

We have only been able to estimate the costs of the engineering component of our flood-management portfolios. The costs of non-engineering responses are much more difficult to evaluate – but they will not be cost-free.

Chart 3.4 details the costs of the engineering that forms part of the portfolios of responses. It can be seen that the range of costs is considerable. This is partly a function of the different amounts of risk that need to be managed in the different scenarios, and partly because some scenarios embody systems of governance which enable non-structural measures, with smaller direct costs, to be more easily used – such as land-use planning.

Chart 3.4 **Additional costs over the next 80 years, of increasing engineered flood defences as part of the integrated portfolio of responses (£ billion)**

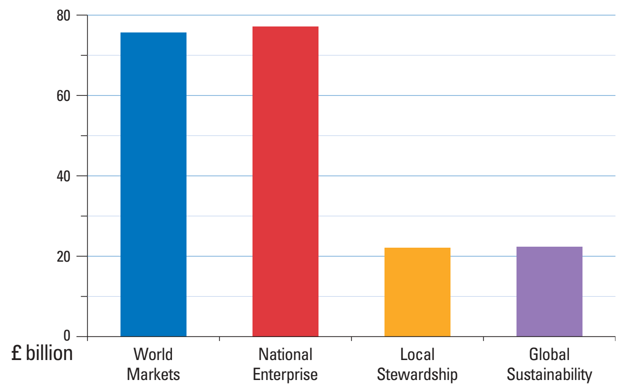


Chart 3.4 details engineering costs for new-build up to the 2080s, to manage fluvial and coastal flooding. Clearly these costs would be spread over the intervening years and would generally increase with increasing risks. This might equate to a compound increase in flood management expenditure of between £10 million and £30 million per year over this period. So, for example, in 20 years, the annual expenditure would be between £700 million and £1.1 billion, compared to £500 million today.

Certain of the non-structural measures were found to be highly effective in reducing risks, and they also scored well on wider sustainability criteria: e.g. building regulation, land-use planning, and rural catchment storage. The key to realising these benefits will be for Government to ensure that the right systems of governance are in place, irrespective of scenario.

We found that some of the most effective measures of reducing flood risk also had adverse social and environmental outcomes. This was inherently true in the two consumerist scenarios, World Markets and National Enterprise. We believe that this conflict can be partly resolved by implementing responses in ways that are sensitive to environmental and social considerations. Such an approach draws upon the values of more than one scenario, in the same way that the future will be a mix of the different scenarios.

How much do we save by adopting an integrated approach – as opposed to just building higher defences?

We considered this question for Global Sustainability in the 2080s. We found that if we used engineering to manage the additional risks, it would cost £52 billion of investment. This compares with £22 billion when using engineering in concert with a range of non-engineering measures. The saving would be offset in some degree by additional costs for the non-engineering measures.

The integrated approach to managing the risks also enables a much more sustainable approach to be realised.

Q13 What about responses to intra-urban flood risk?

Solving the problem of future intra-urban flooding by engineering alone would be prohibitively expensive. Instead, an integrated approach will be vital. However, the results are much more uncertain than the river and coastal case, due to the need for more research and better modelling tools.

Many of the responses we have already considered for broad-scale flooding will assist flood management in the urban environment. Our analysis of intra-urban flood risk therefore concentrated on responses that were specific to the intra-urban environment. These mostly related to engineering, but also included non-structural issues such as regulation.

We found that a combination of different responses would be most effective at reducing risks and cheapest under all scenarios, as it would allow optimisation of the approach used to reduce risks.

In our analysis, the average annual damage for intra-urban flooding was reduced to levels similar to today in the Global Sustainability and Local Stewardship scenarios, with investments in responses costing around £110 million/year and £400 million/year respectively.

Though substantial reductions in annual damage were achieved using responses in the World Markets and National Enterprise scenarios, annual damage remained around ten to fifteen times higher than present-day levels.

It was generally easier to meet sustainability criteria for intra-urban responses than for catchment-scale responses.

Many of the responses that were the most effective at reducing intra-urban risk were also the most uncertain. This contrasts with the catchment-scale and coastal-scale case above, where the picture was more mixed.

Chapter 4

Key choices for policy-makers

Under every scenario, our analysis suggests that if current flood-management policies remain unchanged, the risk of flooding and coastal erosion will increase greatly over the next 30 to 100 years.

Successful management of climate change will reduce significantly the challenges we face in the longer term, and economic growth will determine whether we can afford the costs of flood management. But ultimately it is our decisions that will determine whether we are successful.

Our analysis suggests the best strategy might have three elements: high economic growth, low climate change and making the right choices as a nation. This section highlights the strategic choices that we need to consider.

Q14 What should our aims be for future flood management?

Should we:

- ***Accept increasing levels of risk of flooding.***
- ***Seek to maintain risks at current levels.***
- ***Seek to reduce the risks of flooding?***

If we choose the first option, we could see significant increases in flood damages. This would have undesirable social as well as economic consequences. The third option would require considerable additional investments in flood management. However, our analysis does suggest that the economic benefits would be significantly greater than the costs. In the higher growth scenarios the increases would be less than the economic growth and so would be most easily affordable. Nevertheless, the challenge would remain to find the most efficient way of using our money and the approach that is best for society and the environment.

While the second option – maintaining current risk levels – might seem reasonable, this is set against a trend in society which expects increasing standards of safety and risk reduction. We will not be able to eliminate floods, but society may well expect fewer than at present. A flood can be a traumatic experience for those affected, irrespective of their wealth, so pressure to reduce risk is likely to remain.

In taking the decision, we will need to consider the wider context: how do we want to invest our resources as a nation; and how to get the most benefit from the resources we use for flood management. We will also need to engage the public in decisions on how we invest national resources and what is an acceptable level of risk for the nation.

Q15 How important is managing climate change to the risks we face from flooding, and how best to achieve that?

If we aim to reduce climate change as part of our strategy for managing future risks, it could make the task we face substantially easier.

We can mitigate climate change through controlling emissions or, in the future, by macro-engineering the climate.

Climate change will strongly affect the challenge we face. The probability of flooding increases significantly in the high-emissions scenarios. We looked at the World Markets scenario for both High emissions and Low emissions scenarios – we found that we could reduce the average annual damage by 25% if we achieve the Low emissions scenario. So, reducing climate change will not solve our future flood-risk problems by itself, but it could substantially ease them.

The mitigation of climate change will have limited potential to reduce flood risk by the middle of the century because of time lags within the atmospheric system. However, mitigation would be increasingly significant towards the end of the century as some defences reach their limits. For instance, it could make the difference as to whether the existing drainage and sewer systems in major cities are able to cope with increasing amounts of water. However, international action on mitigation would need to start now to deliver its benefits in time.

Achieving the Low emissions scenario would require either a substantial reduction in emissions of greenhouse-gases or significant investment in technology to macro-engineer the climate.

Q16 What are the additional challenges for our towns and cities?

Changes in risk and the costs of flood management are particularly uncertain in the case of intra-urban flooding. We need to decide how much to invest in better modelling and prediction of flooding in urban areas to ensure that we can plan ahead more effectively.

As well as facing flooding from rivers and the sea, our towns and cities can be flooded by local intense storms which can overwhelm drains and sewers. Our analysis suggests that current methods of flood management would be stretched to maintain risks at current levels, even with substantial increases in investment.

The situation would worsen considerably if the drains and sewers in the UK's cities were to reach the limits of their capacity. If this happened floods would become much more frequent and we would need a substantial investment programme to upgrade sewers, drains and other urban drainage systems. We would need a minimum of 10 to 15 years' warning to prevent significant flood damage and allow efficient upgrades.

It will be important to manage the layout and functioning of our cities so they can adapt to future changes in rainfall patterns. Approaches such as the creation of new green corridors and the maintenance of existing undeveloped spaces (including brownfield) would provide 'safety valves' for the storage and passage of floodwaters when the drainage networks become overloaded. They could also bring substantial sustainability benefits relating to the aesthetic and amenity value of water in towns. However, such schemes might require the abandonment of parts of existing urban areas, with councils and other agencies buying up properties to create new open areas.

The risk of flooding in towns and cities, as well as possibly being our greatest challenge in the future, is also the area of greatest uncertainty. If we want to plan ahead effectively for our cities, we need to develop much better modelling capabilities to predict flooding and manage flood routes in intra-urban areas.

Q17 What factors should inform our long-term approach to flood management?

How we use land, balancing the wider economic, environmental and social needs against creating a legacy of flood risk.

How we manage the balance between state and market forces in decisions on land use.

Whether to implement societal responses with a longer lead time; or rely increasingly on bigger structural flood defences with potential economic, social and environmental costs.

How much emphasis to place on measures that are reversible and those that are highly adaptive.

There are three key issues we need to consider: where to concentrate future urban and economic development, when to invest in flood-risk reduction and how to manage flood risk in those areas.

Where to develop

Influencing where to build houses, factories and other infrastructure emerged as a key tool in managing future flood risks. It is about avoiding building on areas at risk from flooding – or, if building in areas at risk, ensuring, for example, that there is space to allow for river and coastal processes. This approach needs to be balanced against other economic, environmental and social needs, such as the demand for new housing. It also needs to take account of the benefits and disadvantages between, for example, building on brownfield sites, which tend to be on floodplains, and building on land outside floodplains, which may be greenfield locations of landscape or environmental value. There are no easy options.
If decisions are taken to build in areas at risk of flooding, the costs must be recognised and planned for.

Another approach would be to ask developers to provide appropriate flood defences and to allow market forces to determine the location of new developments. This has attractions, but also risks. These include:

- If the developer is asked to provide flood defences at a certain level, will that level be adequate as the climate changes? How much flexibility should they plan for in their initial defences?
- If the developer is asked to maintain flood defences at a certain level, will that developer be around in 50 years to ensure the defences are in good condition?
- If the defences are breached, who will pay? The expectation would be that insurance would provide compensation. However, if faced by a significant loss, the insurers might sue, or the uninsured might pursue a class action suit. While the duty of care would lie with the developer, redress might be sought from the Government.

It should be recognised that the presence of flood defences may, as it has done in the past, stimulate further creeping development and densification, increasing risk in the long term.

When to invest

We found that a portfolio of responses designed for the specific needs of the situation was the most effective way to reduce flood risk. However, different measures have different lead times, some of which are very long. These need to be recognised in any long-term strategy.

Land-use planning is an obvious example. Massive inertia in the built environment means that decisions taken now could take many decades to become fully effective. This will also affect decisions on whether to maintain flood defences in some areas as well as decisions on areas for new build. If an effective way forward is to use the realignment of defences, retreat or even abandonment of some areas, then the sooner long-term plans are in place, the easier it would be for those affected to divest assets with minimum negative impact.

An alternative would be to rely on engineering works later – when it became apparent that they were needed. This could provide short-term savings, but have longer-term sustainability costs if they are eventually built. The lead time for well-planned engineering should not be underestimated. The planning of the Thames tidal defences, to be upgraded by 2030, is starting now. Some risk-reduction measures, such as new flood-warning systems, can be implemented more rapidly. However, raising awareness, so that people respond when they receive a warning, also requires a long-term commitment.

How to manage long-term flood risk

The extreme uncertainty of the future is a major challenge in devising effective long-term flood-management policies. It is important to decide how much flexibility is required to cope with an evolving future, and to choose a portfolio of responses to achieve that. In this respect, reversible and adaptable measures would be the most robust against future uncertainties. Adaptability would include approaches such as: setting aside areas in floodplains that may be used for flood storage if required; building defences to cover the lower limits of our expectations of future flood risk, but providing foundations that would enable the defences to be upgraded if needed.

Q18 What governance issues will we face?

Our strategies and choices *for governance and responses need to be matched with the scale of future risks.*

Governance *(both governmental and non-governmental) needs to support the concept of a portfolio of responses to increasing flood risk, in order to allow its integrated implementation.*

Adaptability *will be important in the portfolio of responses, and its governance arrangements. It is important that the responses can respond to changing societal and climatic drivers.*

Investment *will be needed for future flood and coastal management, to promote long-term solutions, appropriate standards and equitable outcomes.*

Market mechanisms and incentives *should be fully used to manage future risks – while recognising the central role of all levels of government.*

Science and technology *can play a key role in the development of long-term policies in flood-risk management.*

Periodic reassessment *of the long-term strategy for managing flood risk should be made – to take account of new scientific data, and to enable it to be adapted to an evolving future.*

Who pays

There is no simple solution to the question of who should pay for measures to reduce flood risk. Asking developers or beneficiaries to pay could help to ensure that the market takes into account the full costs of new developments. However, there is a need to balance the benefits of passing on the costs of flood management with the need to ensure that the most effective long-term measures are used. Market forces or regulation could lead to a piecemeal, unbalanced approach which could shift the risks of flooding to other places.

The availability of insurance to cover the costs of flood damage will vary depending on changes in risk and society's ability to pay. Cover could range from a continuation of the current situation to progressive withdrawal of cover for areas at greatest risk of flooding. Government might have to consider how to respond to pressure to act as insurer of last resort if the insurance market withdrew cover from large parts of the UK, or if there was a major flood which the insurance market could not cover.

Public perception of risk and acceptance of solutions for the social good

We do not know how public perception of flood risk will change over the next 100 years. We do know, however, that there is a social amplification of risk – society picks up signals of risk from those directly affected by an incident and assumes those risks are uniform in society. Modern communications increases this effect, ensuring a national change in perceptions of a risk following a local event. This is likely to create pressure to maintain current expectations for protection against flooding and may even lead to higher expectations in the long term, even though a wealthier society will be more able to afford the risks.

Decisions on flood management will affect individuals' lives due to a variety of factors, such as planning regulations, the availability of insurance and taxation. Having the best solution as a nation may mean asking some to accept infrequent floods or move. It is not clear what rights individuals will have for risk reduction in the long-term, but such changes in the law could create a significant cost for society as a whole if it is forced to provide a particular standard of flood protection in such situations.

We will need effective dialogue with the public and other stakeholders so that they understand the risks and choices. In particular, they need to appreciate the choices that need to be made, and that there will be a cost whichever path we take. They need to understand that early decisions, before the risk is apparent, may, in the long term, minimise the total costs – economic, social and environmental.

Possible obstacles and opportunities

UK or European legislation on non-flood issues – for example, concerning environmental regulations or social justice – could constrain or close off options for managing future flood risk under certain scenarios. For instance, legislation to protect the flora and fauna in watercourses could limit our freedom to keep river channels clear.

This suggests that implications for managing flood risks could usefully be considered when assessing proposals for international legislation in other areas.

Q19 What are the implications for science and technology?

Should we invest more to ensure better informed decisions on long-term flood management?

Do we need to do more to join up different areas of science?

This chapter has identified many difficult choices that face government. Science and technology can best inform those decisions when the many fields of expertise work together. The Foresight project has shown the benefit in adopting a broad and integrated approach.

The project has identified areas that have the greatest bearing on future risks, but which are also the most uncertain. These fall into three broad categories:

- Reducing uncertainty in risks and responses: e.g. intra-urban precipitation; land-use planning and management.
- Strategic assessment of responses: e.g. strategic risk-assessment for intra-urban flooding; evaluation of non-monetary flood damages.
- Sustainability and Governance: e.g. whole-system costs and benefits; human and ecological consequences of managed realignment and abandonment of defences.

Some of the most important issues are international in nature, and could usefully be considered in multinational research programmes. An example includes the interaction between international governance and long-term flood-risk management.

The Foresight project has itself produced a substantial body of new work that could usefully contribute to the global effort to understand climate change and its implications.

Flood-risk management could benefit from developments in unrelated fields. The challenge is to connect the different areas of science with the flooding community.

The project successfully tested this idea by mounting a workshop on intelligent sensor networks. This identified the defence and transport sectors as leaders in the field. Flood managment could potentially benefit by applying developments to the active management of urban drainage, monitoring of flood defences, and early warning.

Q20 What are the implications for skills?

How do we ensure a sufficient supply of engineers for flood management in the future – and how do we ensure that they have a broad understanding of different areas of science?

There will be a continuing need for civil engineers to contribute to flood risk management – in particular for the design of flood defence works and urban drainage systems. With investments likely to increase, the demand will rise, although the gap between supply and demand is projected to widen, according to a recent study by the Institution of Civil Engineers. It will be important that this gap is managed and that we ensure an adequate supply of good engineers into flood management. A range of other professions were also considered, but skills shortages are not anticipated in any of these.

It was also found that in future, both engineers and other professionals involved in flood-risk management will need to have a wider range of skills to address issues in a holistic way. This implies the need to broaden their skills base.

Chapter 5

Next steps

The publication of the project reports marks the end of the scientific analysis by OST and its team of experts. However, it also heralds the start of a new phase – in which the baton is now passed to Defra and the wider community of stakeholders to consider the implications for policy.

A number of important stakeholders have been studying the findings prior to publication and have already announced a wide range of initiatives. These are being drawn together across Government into an action plan, which will be co-ordinated by Defra. The initiatives fall into the following categories:

- **Considering the implications for policies:** for example, Defra is chairing a cross-Whitehall committee which is overseeing the production of a 20-year strategy for flood and coastal defence for England. Defra has invited the lead project expert onto that committee to ensure that the strategy takes account of Foresight's broad and long-term perspective.
- **Applying and deepening the work in specific parts of the country:** the Environment Agency is already using the work as it considers the future of the Thames Barrier, and the upgrade of London's flood defences. Workshops are also being planned to enable Devolved Administrations to consider and extend aspects of the work for their own regions.
- **Informing research priorities:** the project has identified where further research is most needed to reduce future uncertainty. This information will be made available to research-prioritisation exercises – both within the UK and within the European Union.
- **Informing the climate change agenda:** the work provides unprecedented analysis of the implications of climate change in the important field of flooding. These findings will now be used to inform the climate-change debate within Government and internationally.

Finally, the project has pioneered a new paradigm for combining cutting-edge science and futures analysis to inform policy. In so doing, it has demonstrated the considerable potential of science in informing long-term decisions at the heart of government.

Appendix

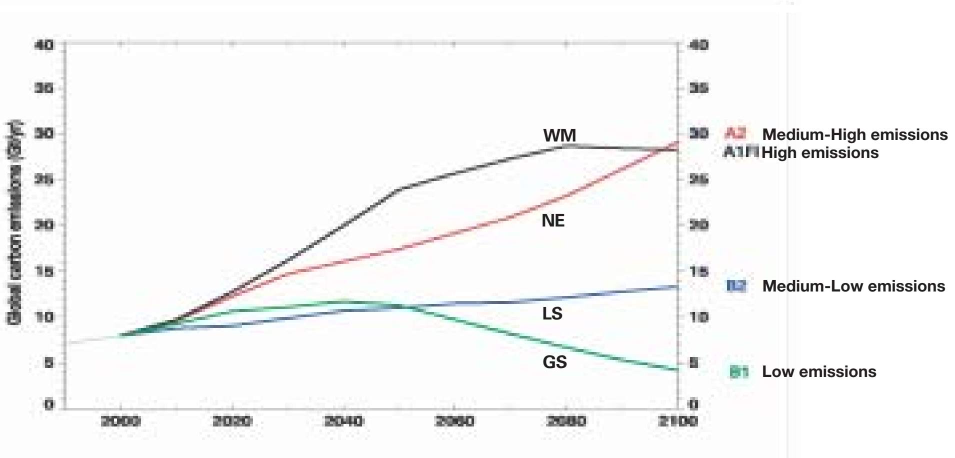
Socioeconomic and climate-change scenarios considered

The characteristics of the socioeconomic and climate change scenario are set out in Table A1 and Figure A1 respectively.

Table A1 **The characteristics of the four future scenarios considered**

	Present day	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
GPD 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
UKCIP global emissions associated with each scenario		High emissions	Medium-High emissions	Medium-Low emissions	Low emissions

Figure A1 **Graphs of the global carbon emissions modelled in the climate change scenarios. (The designation A1F1 etc is in accordance with the Intergovernmental Panel on Climate Change – IPCC)**



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The Office of Science and Technology would like to acknowledge the following individuals who contributed to or reviewed the work of the project. Experts who led the main packages of work are listed in bold:

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The Office of Science and Technology would also like to acknowledge contributions made by the members of the High-Level Stakeholder Group led by Elliot Morley MP, specifically.

High Level Stakeholder Group – members and deputies	
Elliot Morley MP – Chair	Minister for Environment and Agri-Environment
Sir David King	Chief Scientific Adviser to HM Government
Richard Bird	Director, Water Directorate, Defra
Mridul Brivati	Team Leader, Environment, Food and Rural Affairs Team, HM Treasury
Noel Cleary	Head of the Flood Management Strategy Unit, Defra
Alasdair Coates	Operations Director, Halcrow Group Ltd.
Sir Martin Doughty	Chair, English Nature
Professor Chris Fleming	Group Board Director, Halcrow Group Ltd.
Sir Edward Greenwell	Former President, Country Land and Business Association
Brian Hackland	Director, Town and Country Planning, ODPM
Judicaelle Hammond	Environment, Food and Rural Affairs Team, HM Treasury
Sir John Harman	Chairman, Environment Agency
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Anna Longman	Team Leader, Environment, Food and Rural Affairs Team, HM Treasury
Cheryl Miller	Chief Executive Officer, East Sussex County Council representing the Local Government Association
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David Noble OBE	Chief Executive, Association of Drainage Authorities
John Parker	Head of General Insurance, Association of British Insurers
Donald Ritchie	Deputy Chairman, Environment Agency
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Anna Walker	Director General, Land Use and Rural Affairs, Defra
Chris Walker	Assistant Director, Operations, East Sussex County Council representing the Local Government Association
Peter Watts	Chair, Severn Trent Regional Flood Defence Committee

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Expert advisors and deputies	
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David Withrington	Senior Freshwater Officer, English Nature

Flood and Coastal Defence project team	
Robert Bernard	Project co-ordinator
Derek Flynn	Project leader
Jon Parke	Project manager
Neil Pitter	Project administrator
Robert Thornes	Project co-ordinator

List of project reports

The following project reports and documents are available from the OST or from the Foresight website – *www.foresight.gov.uk* :

1. *Executive Summary*

2. *Key messages for stakeholders:* this is a series of information sheets for researchers, skills providers, local and regional government, and the insurance and financial services.

3. An overview of the science used may be found in:
   Scientific Summary: Volume I – Future risks and their drivers
   Scientific Summary: Volume II – Managing future risks

4. *Scotland*. This is a detailed technical report analysing the extent and nature of future risks specifically for Scotland.

5. A series of technical papers detailing the underlying work of the project.

6. *FloodRanger* flooding simulator: this computer based educative tool enables the operator to explore the interaction of many issues relating to future flood defence for an imaginary part of the UK – including climate change, planning, infrastructure provision and flood defences. It is of potential interest to educators and professionals interested in flooding and its interaction with society, the environment and the economy. Further details of FloodRanger are available from the developers: *www.discoverysoftware.co.uk*

Other Foresight projects

Foresight runs a rolling programme of up to four projects at a time. Each produces challenging visions of the future to ensure effective strategies now. So far four other projects have been started, all taking an authoritative view of the science in relevant areas, combined with a forward look at what science and society could deliver us over the next 10 to 20 years.

Like the flooding study, two of the other projects are centred around key challenges. The Cyber Trust and Crime Prevention project is looking at the implications of next-generation information technology for crime and crime prevention and the factors that influence trust in a digital age. The Brain Science, Addiction and Drugs project is exploring potential opportunities and challenges from research on addiction and drugs that affect the brain.

The other two projects focused on scientific advances, looking for opportunities for exciting new areas for research and commercial exploitation. The Cognitive Systems project identified opportunities for closer collaboration between scientists working on intelligence in living systems and those working on building intelligence into artificial systems. The Exploiting the Electromagnetic Spectrum project identified four key areas of long-term commercial opportunity across the spectrum, assessed these against UK capabilities and agreed a plan of action to help the UK exploit them.

Further Foresight projects will be launched during 2004.

Further information can be found on the Foresight website at **www.foresight.gov.uk**

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